STUDY OF CONCRETE FRACTURE SIMULATION USING ANSYS

By

AZREE AZHAR BIN AWI

FINAL PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

December 2008

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.

Azree Azhar Bin Awi

ABSTRACT

Major problem in concrete is fracture due to excess load acting on it or failure due to tension or shear. This project focused on the computer simulation of concrete fracture using ANSYS software. Though, ANSYS software helps simulate the cracking and concrete fracture simulation in calculating the most important stress intensity factor using in-built crack analysis engine. Using several perimeters and different type of load, several types of fracture will be getting. A concrete fracture model is analyzed to find the precise results in order to simulate through this project. Finite-element Method is being used in this studies and Linear Elastic Fracture Model is recognized to be the most efficient fracture model to be used in ANSYS. This study of simulation will be beneficial to all in a way to have better understanding of concrete fracture occurrence and this is important in big construction companies which use concrete as their core material construction..

ACKNOWLEDGEMENTS

All praises to Allah, the Almighty for enabling the author to have the courage and determination to complete the one year Final Year Project with success. The author would like to express his heartfelt thanks and gratitude to;

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- Mr. Julendra, post graduate student from Mechanical Engineering Department for always helping me during lab sessions
- To all individuals that has helped the author in any way, but whose name is not mentioned here,

The author shall always remain deeply indebted to all of you and thank you very much

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ANSYS – Analysis System (SOFTWARE)

CHAPTER 1
INTRODUCTION

1.1 Background of study

For aged, there is no direct way to predict fracture pattern in concrete. Many fracture mechanics theories have been idealized but that's only limited to brittle materials such as glass and steel. Just a decade ago, concrete fracture mechanics has been found which concrete is a quasi-brittle material and yet to have double material properties.[2]

From the finding of Concrete Fracture Mechanics, it had gives many benefits to researchers as well as building developers. As a matter of fact, it is the crack pattern theory in Concrete Fracture Mechanics which has influence the structural and concrete design nowadays

Since its discovery, there are many laboratory tests related to concrete fracture. However, it is just a physical test and people must use their own eyes to locate the crack. With the development of new technology, people can now use computer-aided software to analyze the formation of crack within the concrete structure and also the most important critical stress intensity factor which lead to fracture. This is more accurate and very precise because it gives the computer to calculate itself and to simulate the crack occurrence, which human beings cannot see by naked eyes.

From the usage of this new technology, we achieve to move one step ahead in civil engineering since the discovery of Fracture Mechanics and from that matter, produced more quality buildings and more strength in structural integrity.

1.2 Problem Statement

Fracture is defined as a cracking at the structure whenever there is excess load. In this case, concrete fracture is brittle. Concrete are prone to cracking because they are weak in tension. In our case, we can find the fracture parameter of a structure by finding its stress intensity factor and displacement at crack tip. However, normal laboratory methods are prone to errors and machines defections. Hence a method needed to solve this problem in assisting to predict the fracture.

1.3 Objectives

- To assist the manual way of finding the fracture parameters of concrete.
- To analyze the concrete fracture pattern throughout the fracture simulation.
- To reduce human errors in analyzing the concrete fracture theory
- To locate the displacement at the crack tip at the point when fracture occur.

1.4 Scope of study

- Determining point of fracture of several different composition of concrete using NODE8 and SOLID20.
- Shape and size factor that affecting stress and stress in concrete.
- Determining the stress intensity factor in ANSYS using PLANE82 element type.

1.5 Feasibility

Considering the existing problems faced in the industry relating to the concrete fracture simulation. Improvements should be made to the methods of simulating the fracture pattern. By accurately predicting the cracking pattern behavior in the concrete, the civil engineers can conduct their planning and development more precisely to increase the effectiveness of the results. With the improvements, possible increase in crack analysis accuracy should be achieved. Thus, results in prolonging the lifespan of a concrete structure. Therefore, this project is feasible for study to improve the current trend in the industry.

1.6 Relevancy

This project is relevant to the civil industry especially to the civil engineers in assisting them to analyze accurately the occurrence of crack in the concrete structure. Despite the fact that actual laboratory fracture test is still conducted, proper simulation using the computer-aided software will help to analyze more which we cannot get from actual laboratory works. With effective execution of simulation, the final pattern of concrete structure can be improved

CHAPTER 2
LITERATURE REVIEW

This chapter cover the important theories involve in concrete fracture simulation.

2.1 Concrete Characteristics

Concrete and steel are different types of construction material. Steel is different in cracking because it is a fatigue crack which in turn produces ductile fracture. Ductile fracture means the crack is also deforming in shape and size. However, concrete fracture is considered brittle fracture. Brittle fracture means the crack is not followed by any deformations around the crack

Concrete is not a material that we can found in the earth originally like gold or aluminium. It is a combined ingredient of water, cement and aggregates. Some people misunderstand of cement with concrete. Cement is a material that binds other materials together. In concrete, it binds the water and aggregates to make it hardened. The formula for making concrete is:[1]

PORTLAND CEMENT + WATER + AGGREGATES = HARDENED CONCRETE + ENERGY(HEAT)

Usually Portland Cement is used in the making of concrete. Portland cement is a mixture of processed limestone, shale, and clays which contain the following compounds: CaO (lime), Al_2O_3 (Alumina),SiO_2 (silica) and iron oxides.

The strength of concrete is determined by the proportion of water content and aggregates. Some properties of concrete composition:

Table 1 Typical Concrete Composition

Typical Composition by Volume	
Cement	7-15%
Water	14-21%
Aggregates	60-80%

2.2 General Fracture Pattern

When talk about fracture, there is several patterns of fracture. Basically there are 3 modes of fracture, depending on the forces acting on the concrete.[1]

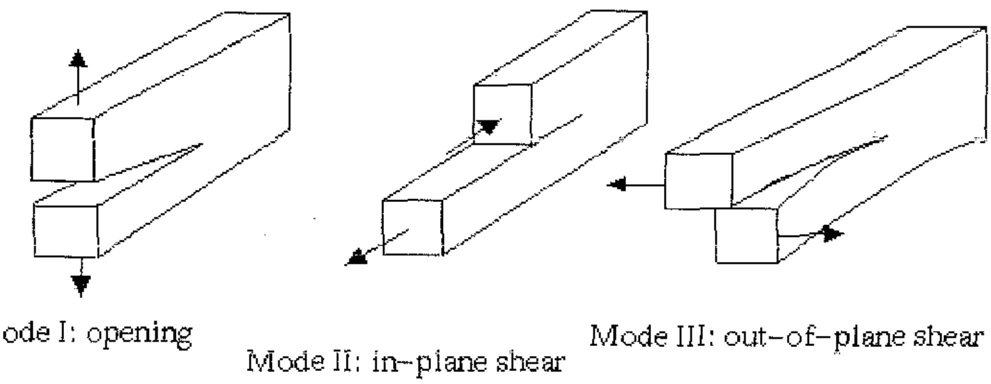


Figure 1 : Mode of Concrete Fracture Pattern(Du et al, 1988)

Mode 1: The forces are perpendicular to the crack (the crack is horizontal and the forces are vertical), pulling the crack open.

Mode 2: The forces are parallel to the crack. One force is pushing the top half of the crack back and the other is pulling the bottom half of the crack forward, along the same line.

Mode 3: The forces are perpendicular to the crack (the crack is in front-back direction, the forces are pulling left and right

These are the common modes of concrete fracture pattern and most widely used in predicting the occurrence of crack in concrete structure design.[1]

2.3 Fracture Mechanics of Concrete

When talk about concrete fracture mechanics, the main thing we mustn't forget is that we must find:

1. Stress intensity factor along the crack

2. Displacement at crack tip.

All the calculations are based on the relative opening, sliding and tearing displacements derived from an orthogonal set of axes at each crack front node, as shown in the example below for a symmetry model. These relative displacements are used to calculate the stress intensity factors using equations derived from the Westergaard solution for the stress field around a crack tip. The equations that are used are valid for linear elastic isotropic materials (LEFM).(shah,1991)

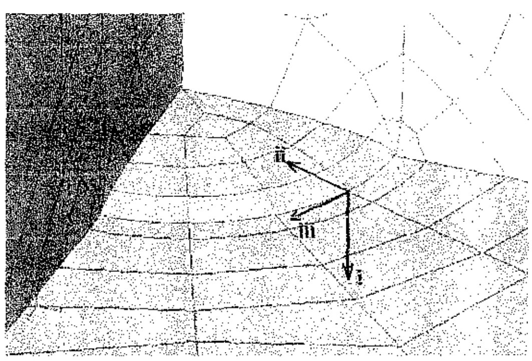


Figure 2 ; Stress intensity factor of Mode I, Mode II and Mode III(zentech,2006)

$$K_I = \sqrt{2\pi}\,\frac{G}{1+\kappa}\,\frac{|\Delta v|}{\sqrt{r}}$$

$$K_{II} = \sqrt{2\pi}\,\frac{G}{1+\kappa}\,\frac{|\Delta u|}{\sqrt{r}}$$

$$K_{III} = \sqrt{2\pi}\,\frac{G}{1+\kappa}\,\frac{|\Delta w|}{\sqrt{r}}$$

u, v, w = displacements in a local Cartesian coordinate system.

r, θ = coordinates in a local cylindrical coordinate system.

G = shear modulus

K_I, K_{II}, K_{III} = stress intensity factors related to deformation mode

ν = Poisson's ratio

Δv, Δu, and Δw = the motions of one crack face with respect to the other (Shah,1991)

However, concrete fracture mechanics can be simplified into this flow to make it more understandable. It starts when the load increase the stress in the structure. Frankly, when the stress reach the maximum tensile strength ,ft, the stress inside the concrete starts descending because of the occurrence of fracture zone (also known as process zone) and unloads the material outside the process zone area.(Du et al,1987)

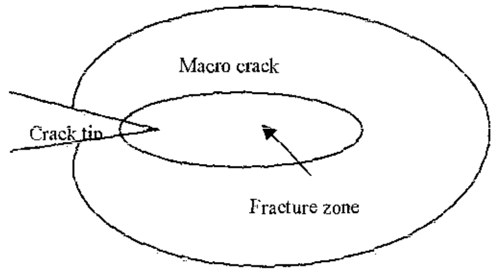


Figure 3 : Typical fracture zone in concrete[4](Du et al,1987)

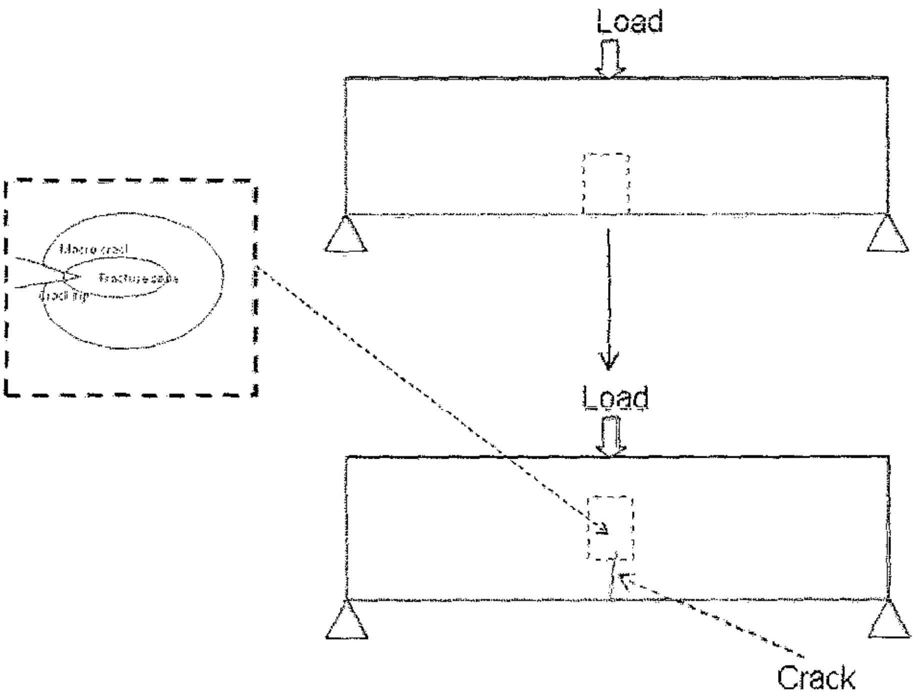


Figure 4 : Fracture Process Flow Diagram(Du et al,1987)

Then the strains begin to decrease based on the stress-strain diagram which is the unloading branch specifically. The material is unloaded and the strains begin to decrease as well. At this time, in the process zone, the deformations increase simultaneously(Du et al,1987)

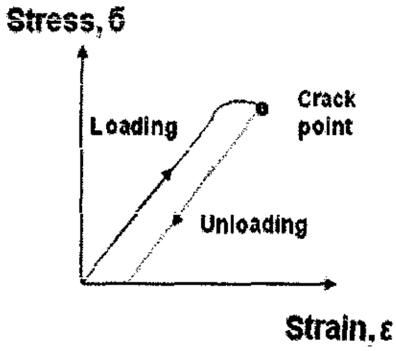


Figure 5 : Typical stress-strain relationship(Du et al,1987)

There are two main curves involve in the fracture mechanic of concrete. One is stress-strain curve which is applicable to most of the materials and another one would be stress-deformation curve which shows the deformations occur within the process zone. Stress-strain diagram also included with unloading branch. Meanwhile, stress-deformation diagram can be used to calculate the fracture energy, Gf, in the fracture zone by looking at its area under the curve. It is a sign of how tough the material would be. The higher the value of fracture energy in the material, the material is better in toughness. Toughness is important criterion in determining the tensile failure of the material.(Du et al,1987)

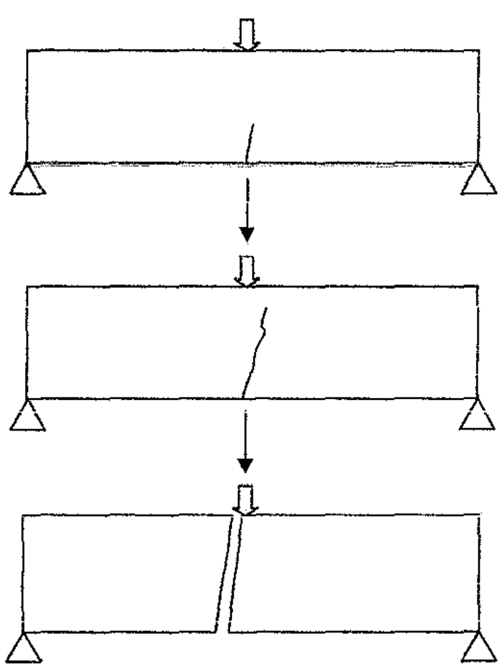


Figure 6 : Typical fracture propagation of concrete(Du et al,1987)

2.4 Comparisons of Concrete Fracture Models

Concrete fracture models can be divided into several types. However, there are three types of fracture models that are commonly being used in laboratory. Those are: Linear Elastic Fracture Mechanics (LEFM) model, Singular Fracture Process Zone(S-FPZ) and nonsingular Fracture Process Zone (NS-FPZ). All of these models' properties are determined from three-point bend tests. (Yon,1997)

LEFM is one of the models which are based on brittle materials and it is assumed that concrete to be a linear elastic model and when the strain energy release rate, G, or the stress intensity factor, K, reaches a critical value, Gc or Kc, the crack will propagates. (Yon,1997)

In NS-FPZ model, which is proposed as fictitious crack model (Hillerborg, 1976), the stress at the micro crack tip is assumed as continuous and micro crack tip was trailed by fracture process zone (FPZ). The crack faces which being transferred with tensile stresses is taken as discrete crack. Crack closure stress (CCS), also defined as amount of stress transferred depends upon the crack opening displacement (COD). Maximum CCS is taken as the tensile strength of the concrete and become the fracture criterion. To be simplified, CCS-COD relationship is the basic fracture property of the NS-FPZ model

Another model, which is the S-FPZ model (Yon, 1991), combined the characteristic of both the LEFM and NS-FPZ models. The micro crack tip is assumed as discontinuous and prediction of fracture is by using singularity at the micro crack tip, which is same with LEFM. However, basic fracture properties of the S-FPZ model still using the same parameter with NS-FPZ which is the CCS-COD relationship.

The simplified characteristics of each model are portrayed in the following table:

Table 2 : Concrete Fracture Model(Yon,1997)

Fracture model (1)	Fracture criterion (2)	Stress at crack tip (3)	Fracture process zone (4)	COD shape (5)
LEFM model	G_c or K_c	discontinuous	traction free	blunt
S-FPZ model	G_c or K_c	discontinuous	CCS-COD relation	depend on K_c
NS-FPZ model	f_{ccs0} or F_t	continuous	CCS-COD relation	sharp

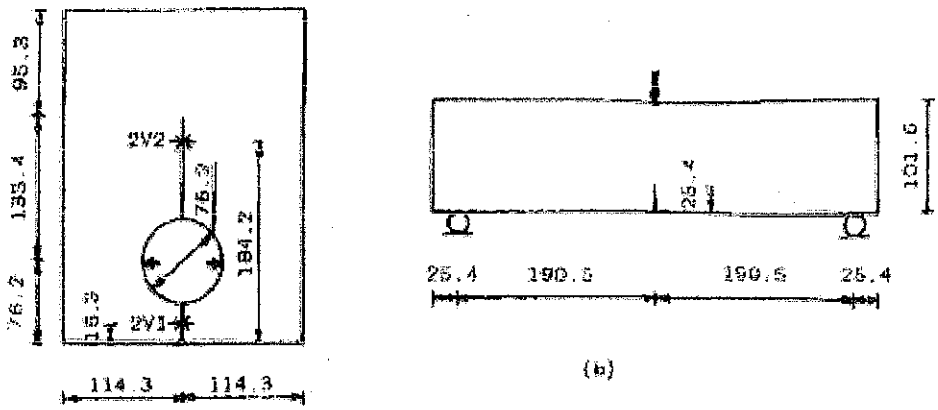
Note: f_{ccs0} = the maximum crack closure stress; F_t = tensile strength.

In order to analyze these models, finite element method was used. The models are assumed to be using linear elastic, four node quadrilateral elements. Testing was based on three-point bend test. From findings, measured load and CMOD versus load-point displacement relation can be achieved by all the models. Total fracture energy for including strain energy release rate was similar between NS-FPZ model and S-FPZ model even though fracture energy density in NS-FPZ was larger. LEFM model has the largest resistance and NS-FPZ model has the least for crack extension. In this project's simulation, LEFM is used as base-model to find the stress intensity factor.(Yon,1997)

2.5 Direct Finite Element Method (FEM) Analysis of Concrete Fracture Specimen

Fracture Process Zone (FPZ) model can be used to predict accurately the global specimen behavior, Crack Opening Displacement (COD) and crack growth behavior for concrete specimens subjected to either static or dynamic loading. The specimen geometry effects, boundary effects, and the effects of the overall stress state on the constitutive equation, which relates the crack closure stress to the COD, is determined by measurements other than the direct tension specimens.(Du et al,1988)

Two specimens are tested: a) small CLWL-DCB specimen and b) large beam specimen:



(a)

Figure 7 : FEM analysis specimens(Du et al,1988)

Concrete fracture specimens of two different geometries, the CLWL-DCB specimens and the three point bend specimen were analyzed using FEM numerical procedure. The mechanical properties of the concrete were determined and the crack opening displacements along the fracture process zone were measured using moiré interferometers (Du et al. 1987). The meshed diagrams for specimens are portrayed below:

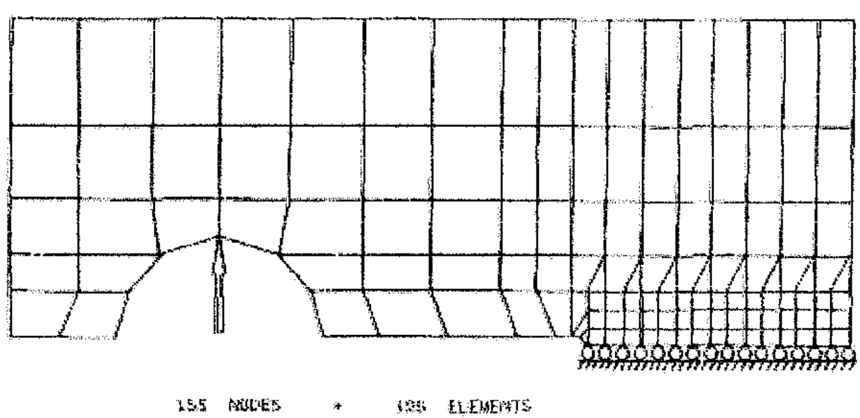


Figure 8 : Finite Element Mesh for CLWL-DCB specimen(Du et al.1988)

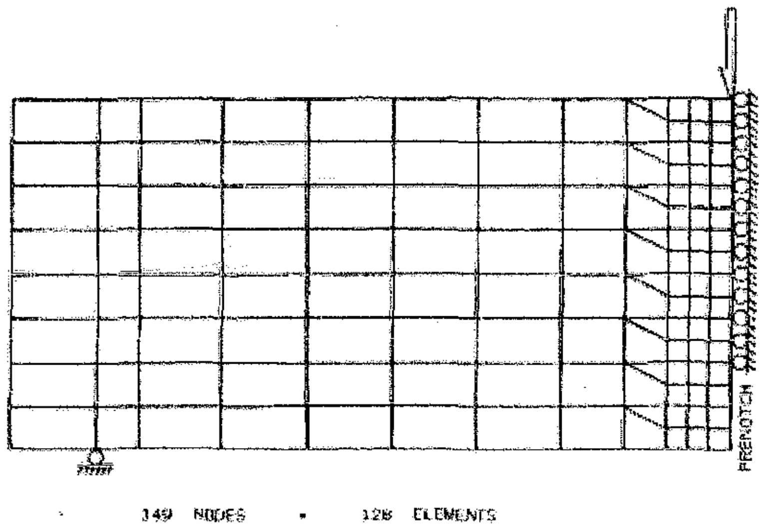


Figure 9 :Finite Element Mesh for three-point bend specimen(Du et al,1988)

In this finite element analysis, four-node isoperimetric elements were used (PLANE82). The results for crack closure stress versus crack opening displacement are illustrated in the following diagram:

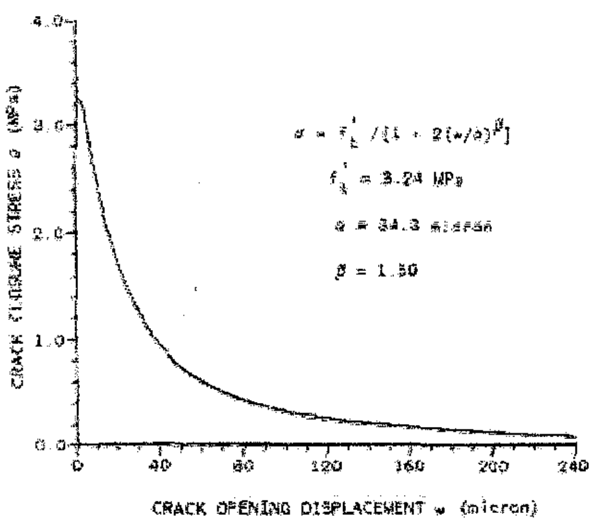


Figure 10 : Crack closure stress versus COD – One continuous Model (Du et al.1988)

Thorough this analysis, it is found that this method can predict accurately the CCS and COD through comparison of experimental and numerical results. Besides analyzing the fracture pattern, this method is able to predict stress distributions and energy partitions as well. Therefore, FEM analysis is the best way in simulating concrete fracture using ANSYS later on.(Du et al,1988)

CHAPTER 3
METHODOLOGY

This chapter discuss the methods and procedures that being used in running this project.

3.1 Project Work Flow

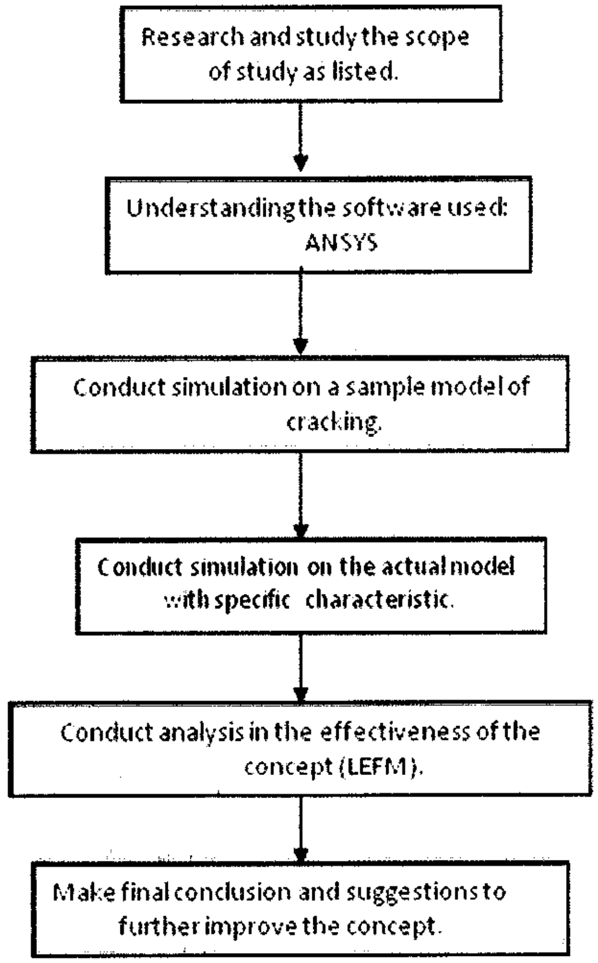


Figure 11 : Project Flow Chart

3.2 Research Stages Breakdown

This research is divided into 3 stages:

3.2.1 Stage 1: Literature Review on the related subject.

As the start of the research project, an extensive literature review has to be done in order to fully understand the concept of the project. A wide range of knowledge is needed for the project to be successful. In this stage, we have to grasp all the information that is related to the project by conducting research and studies from every single source. These sources can be taken from the journals, papers from the internet and library, companies' website that is related to the industry, reference books recommended by the supervisors, and potential sources from companies in the industry.

The literature review for this project will mainly focus on the Concrete Fracture Mechanics especially the different types of concrete fracture, different concrete characteristics that affect the cracking behavior in concrete, software used in the industry to conduct structural simulation, current technologies used, and the equations used in the simulation of the concrete. Most importantly, further improvement of the current system has to be identified during the literature review stage in order to implement it in the later stage of the project.

3.2.2 Stage 2: Learn and Practice the ANSYS Software and Conducting the Simulation

At this stage of the research, basic understanding of how the software works should have been already obtained through the process of literature review. Currently in the market there are several software used for the purpose of concrete. Out of the many choices of simulators, the simulator that is going to be studied will be the ANSYS software by Ansys Inc. This is due to the fact that this software is widely used in Malaysia and the accuracy of the software.

The manual of the software will be obtained and studied in order to familiarize with the software. Basic tutorial can be conducted and request from the lecturer to better understand the software. Mock up training will be conducted on personal initiative to further improve the skill in the software to save more time during actual simulation work being done.

Simulation work on a simple self-created model will be conducted on different characteristic of concrete to understand more on the concrete cracking pattern. The actual model of concrete fracture results will be obtained from the UTP laboratory to be compared with actual simulation. After getting the parallel results of actual model and actual simulation, more fracture simulations on different characteristics of concrete will be conducted.

3.2.3 Stage 3: Analysis and Conclusion of the Research Project

After conducting all the studies and actual simulation work with the improved ideas, a thorough analysis of the worthiness of the idea is to be investigated. This analysis will include the cost factor and the effectiveness of the new idea. The analysis will include basic knowledge in strategic management and engineering economics.

Besides conducting the analysis, further suggestions on improvements of the ideas will also be included. The final purpose of this project is to develop a virtual laboratory in UTP to conduct simulations on concrete, without going to have actual laboratory works. This will save UTP from going to waste lab materials just to conduct cracking test.

The research project will be concluded accordingly as stated in the objective of this project whereby the characteristics of the concrete will be understood and lead to a full understanding of a method used to accurately make assumptions to be applied on a concrete fracture pattern

3.3 Proposed beam sketch design and properties

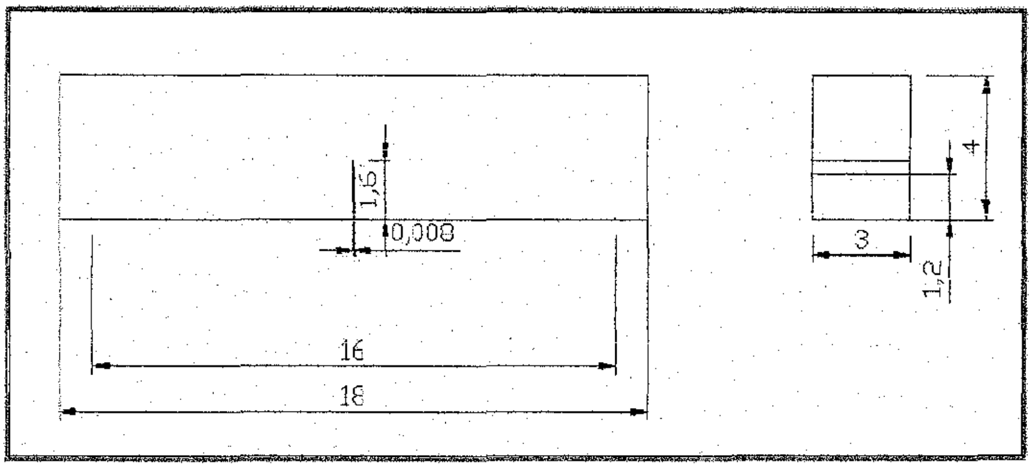


Figure 12 : Dimensions of design of beam

Table 3 : Properties of Concrete Model

Unit System	Metric (m, kg, N, °C, s, V, A)
Angle	Degrees
Rotational Velocity	rad/s
Object Name	*Solid*
State	Meshed
Graphics Properties	
Visible	Yes
Transparency	1
Definition	
Suppressed	No
Material	Concrete
Stiffness Behavior	Rigid
Nonlinear Material Effects	Yes
Object Name	*Crack Analysis*
State	Fully Defined
Definition	
Physics Type	Structural

Analysis Type	Crack Analysis
Options	
Reference Temp	22. °C
Structural	
Young's Modulus	3.e+010 Pa
Poisson's Ratio	0.18
Density	2300. kg/m³
Thermal Expansion	1.4e-005 1/°C
Tensile Yield Strength	0. Pa
Compressive Yield Strength	0. Pa
Tensile Ultimate Strength	5.e+006 Pa
Compressive Ultimate Strength	4.1e+007 Pa
Thermal	
Thermal Conductivity	0.72 W/m·°C
Specific Heat	780. J/kg·°C

3.4 Tools and Equipments

The main tool that will be used in this project will be the computer in the simulation lab installed with the ANSYS software. This software is being used in PETRONAS and UTP. Therefore, it is feasible to conduct the simulation using this software with the availability of the software license

3.5 Hazard Analysis

As the project involve mostly in computer simulation, several hazards may occur due to electronic problems or haywire. The screen may affect the eyes of the beholders as it produced the ultraviolet ray which is harmful. Other type of hazard is like electric shock and the author will takes serious precaution to prevent this thing from happen.

CHAPTER 4
RESULTS AND DISCUSSIONS

All the results are portrayed here together with the discussions.

4.1 Meshed Model

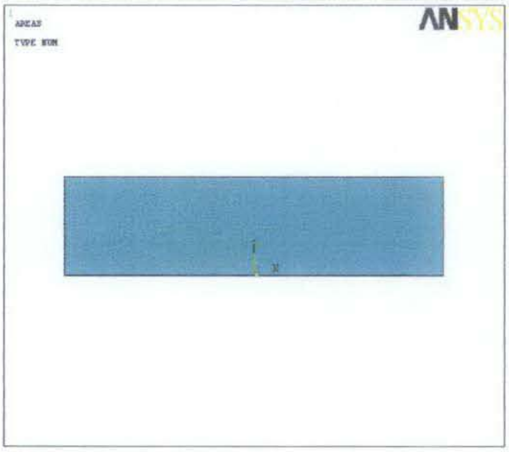


Figure 13 : Before meshed

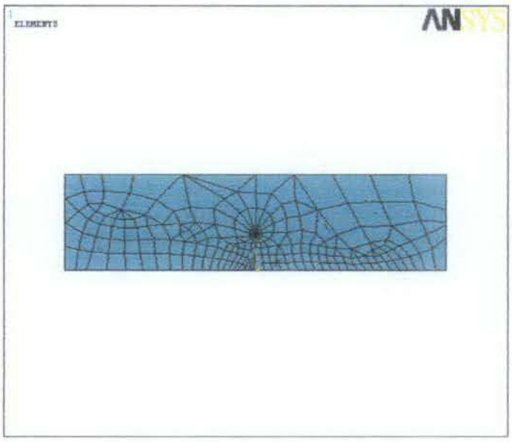


Figure 14 : After meshed

Look after the beam had been meshed. The contour is not uniform which indicate the mixing ingredient in concrete.

4.2 Stress Intensity Factor

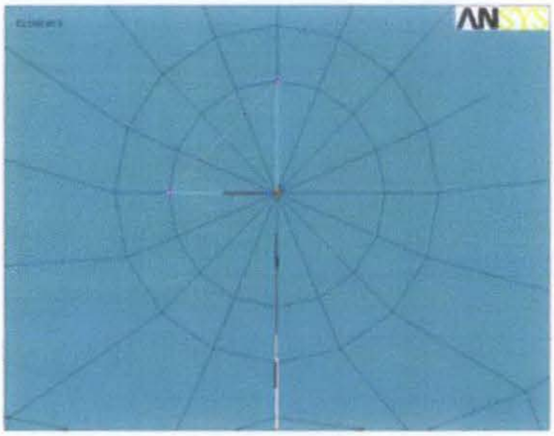


Figure 15 : Stress Intensity at crack surface

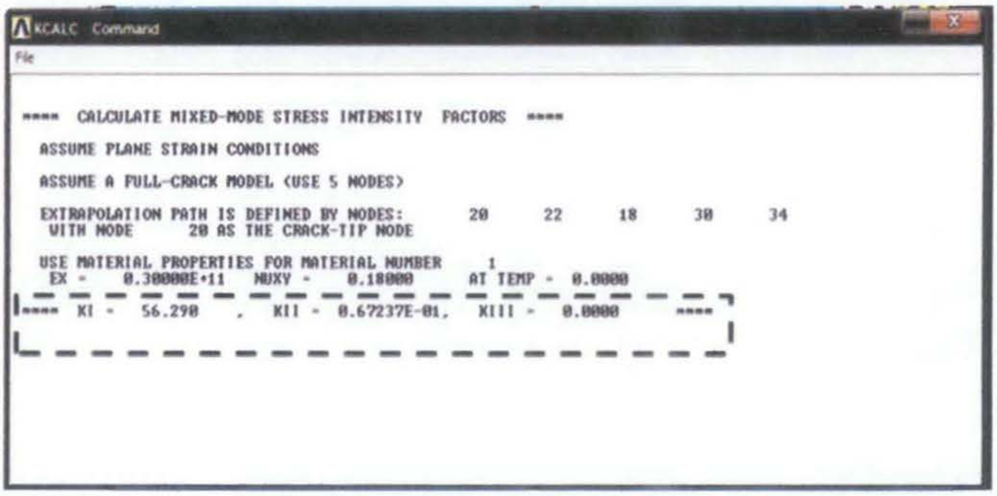


Figure 16 : Results of Stress Intensity Factor using KCALC command

From above analysis using ANSYS;

KI = 1.77, MPa m1/2 KII = 0.0002 MPa m1/2 KIII = 0 MPa m1/2

The important value in stress intensity factor is the value of Ki which is 1.77MPA $m^{1/2}$. We get the value by dividing the original Ki of 56.290 with 31.66 so that the unit conversion will be in the correct form. According to research done by Shah S. P. (1991), the average critical stress intensity factor for fracture to occur is between 0.93 to 1.53 MPA $m^{1/2}$ for normal concrete. We get a slightly higher than the range because the difference in our dimensions and applied load. Therefore, the slight difference is negligible. A full crack model is used as it is more accurate compared to half model and the temperature is not required (assume 20°C)

4.3 Max Deflection

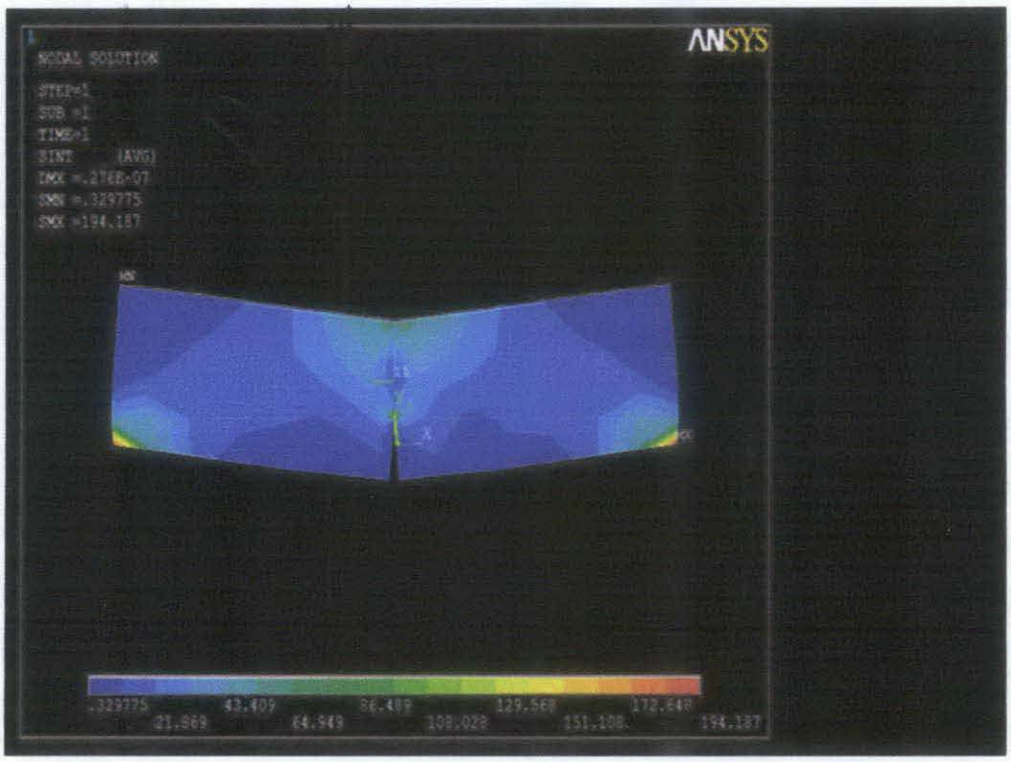


Figure 17 : Max deflection of analysis

<u>From above analysis using ANSYS;</u>

The maximum deflection is 2.76 E-08 at the crack tip.

4.4 Min/Max Axial Stress Intensity

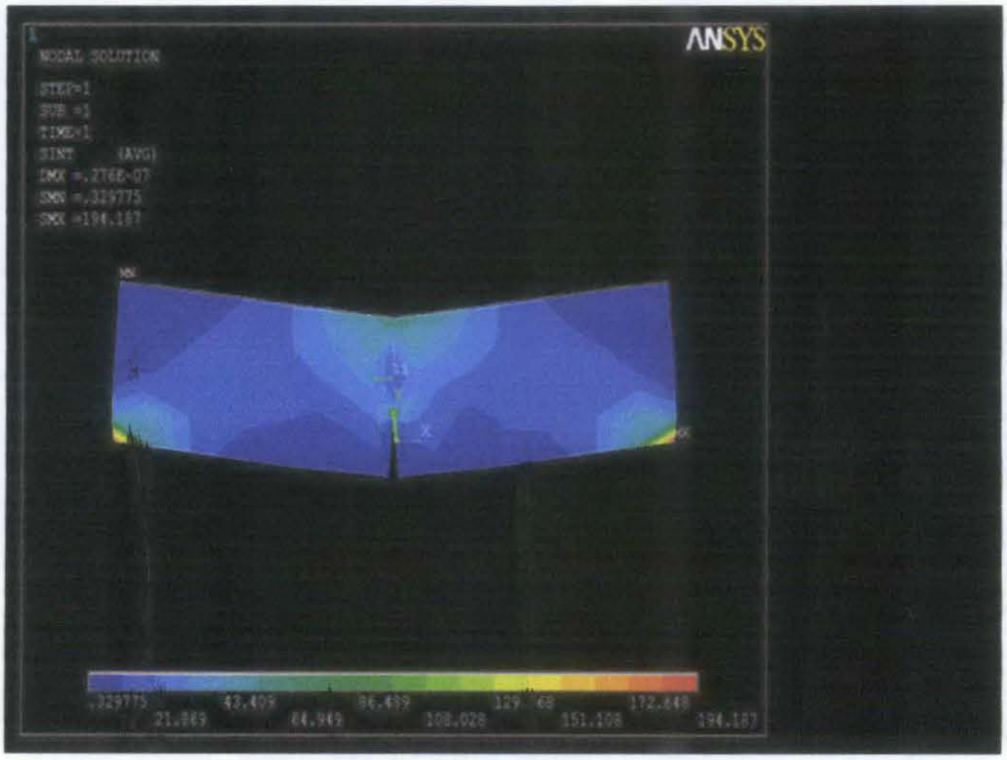


Figure 18 : Min/Max axial stress intensity

From above analysis using ANSYS;

The maximum axial stress is 194.187 MPa $mm^{1/2}$

The minimum axial stress is 0.329775 MPa $mm^{1/2}$.

4.5 Min/max Elastic Strain Intensity

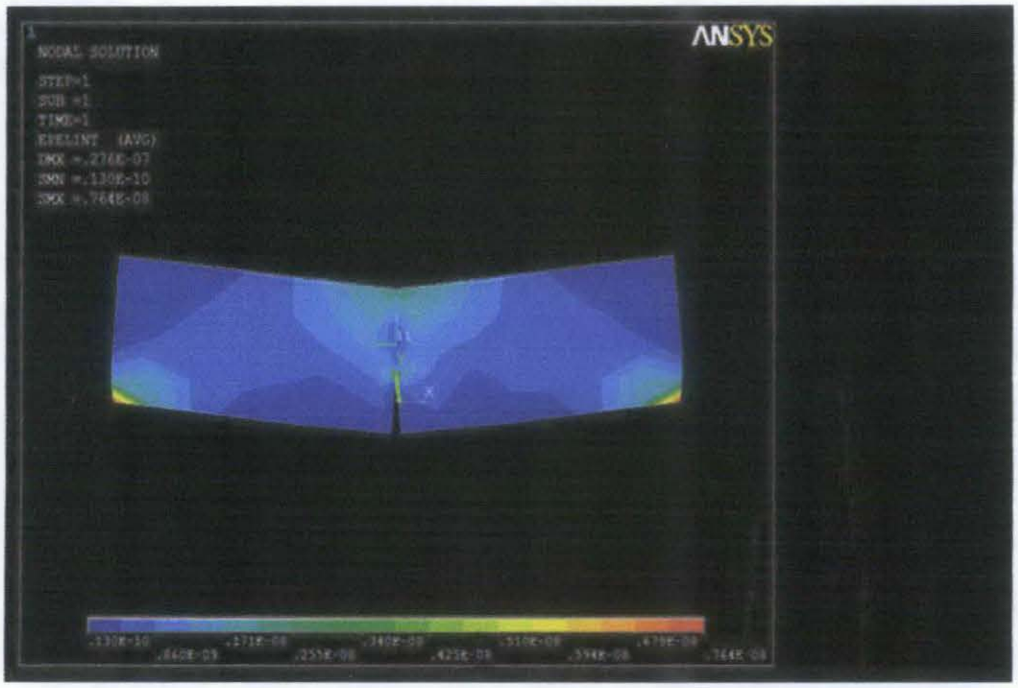


Figure 19 : Min/max Elastic Strain Intensity

From above analysis using ANSYS;

The minimum axial stress is 0.13E-010 MPa $mm^{1/2}$

The maximum axial stress is 0.764E-08 MPa $mm^{1/2}$

4.6 Von Misses Stress

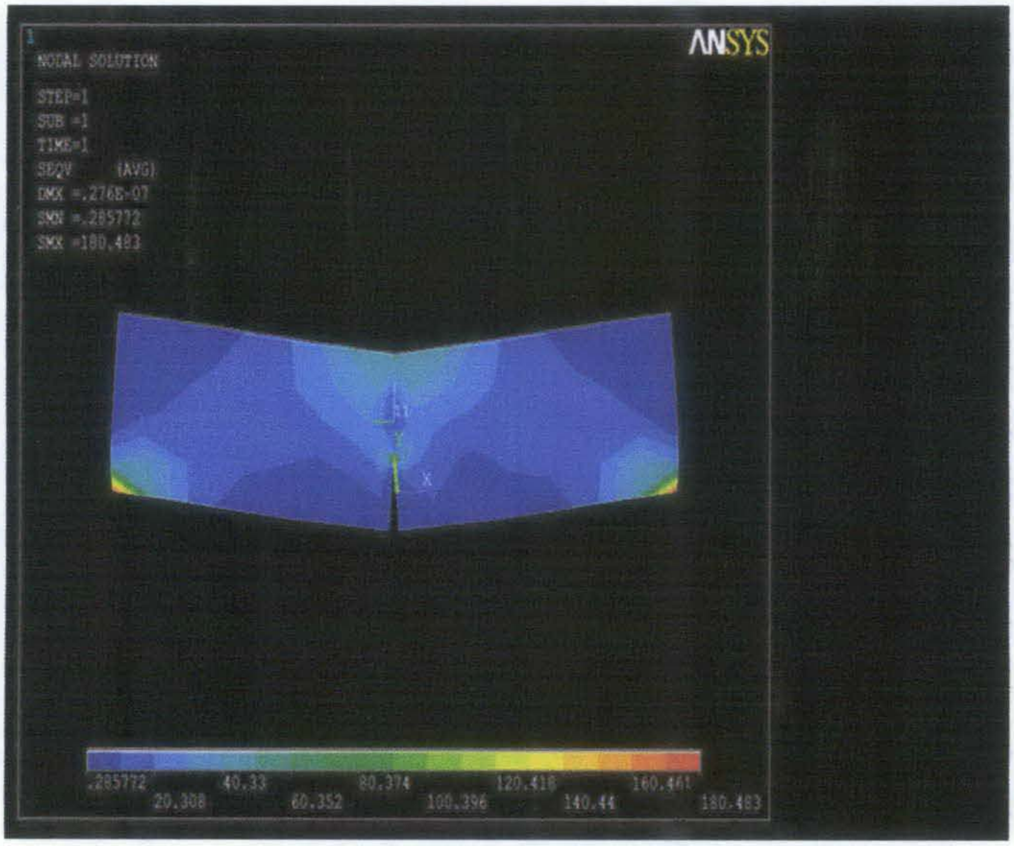


Figure 20 : Von Misses Stress Analysis.

From above analysis using ANSYS;

The minimum axial stress is 0.285 MPa

The maximum axial stress is 180.483 MPa.

4.7 Von Misses Strain

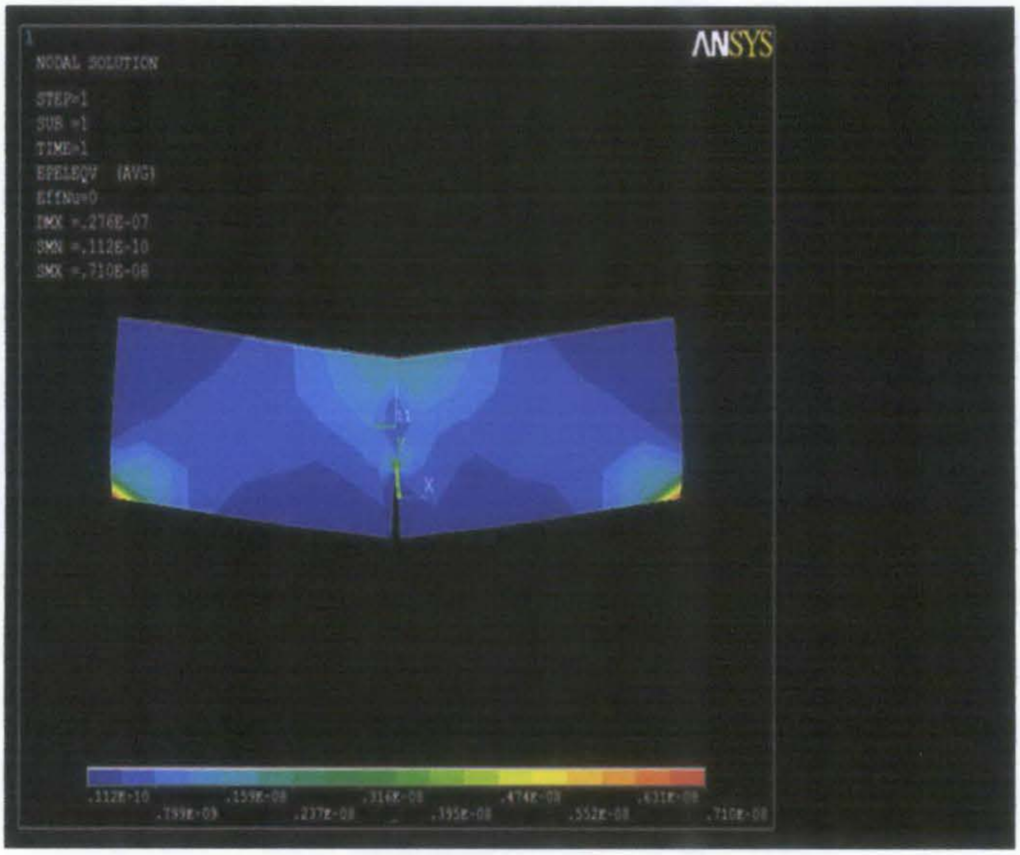


Figure 21 : Von Misses Strain Analysis.

From above analysis using ANSYS;

The minimum axial stress is 0.112E-010 MPa

The maximum axial stress is 0.710E-08 MPa

CHAPTER 5
CONCLUSION

This chapter is to conclude all the findings and results

5.1 Conclusion

1. Based on the results obtained, the stress intensity factor is **K_I = 1.77, MPa $m_{1/2}$** which is acceptable for fracture to occur in the beam. The normal acceptable range for critical stress intensity factor is between 0.93 to 1.53 MPA $m^{1/2}$ for normal concrete (Shah, 1991).

2. In this project, Linear Elastic Fracture Model(LEFM) was used to calculate the stress intensity factor of the beam, the deflection and axial stress.

3. PLANE82 is chosen to be the material element type. This element provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries.

4. The modulus of elasticity for the beam is set at 3.0E+010 MPA while the poisson's ratio is 0.18.

5. Other method of fracture mechanics also can be used instead of LEFM method.

6. ANSYS reach the target to analyze fracture mechanics theory. Another way to try implementing fracture mechanics in ANSYS is by using CCS-COD relationship.

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APPENDICES

Appendix A – Project Gantt-Chart

APPENDIX A

PROJECT GANTT-CHART

Suggested Milestone for the 1st Semester of 2-Semester Final Year Project (Civil Engineering)																
No.	**Details / Week**	**1**	**2**	**3**	**4**	**5**	**6**	**7**		**8**	**9**	**10**	**11**	**12**	**13**	**14**
1.	Selection of Project Topic								M							
2.	Data gathering and research on topic								I							
3.	Submission of Preliminary Report								D							
4.	Identify areas of improvements								S							
5.	Familiarization of simulation software								E							
6.	Construct software work flow								M							
7.	Conduct simulation using simple model-2D															
9.	Submission of Progress Report								B							
11.	Submission of Interim Report Final Draft								R							
12.	Preparation for presentation								E							
13.	Oral Presentation								A K							

Suggested Milestone for the 2nd Semester of 2-Semester Final Year Project (Civil Engineering)

No.	Details / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1.	Formation of new concept of simulating								M							
2.	Conduct simulation on actual concrete fracture model using the formulated concept								I D							
3.	Submission of Progress Report 1															
4.	Submission of Progress Report 2								S							
5.	Talk								E							
6.	Analysis of actual simulation results with the formulated concept.								M							
7.	Analysis of feasibility of the new concept															
8.	Preparation for poster, presentation and conclusion								B							
9.	Poster Exhibition								R							
10.	Submission of Dissertation (soft bound)								E							
11.	Oral Presentation								A							
12.	Submission of Project Dissertation (Hard Bound)								K							