

DYNAMIC ANALYSIS  
OF  
ADOBE STRUCTURE  
WITH  
BILINEAR MATERIAL MODELLING

LYE JIUN YIN

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

## UNIVERSITI MALAYSIA PAHANG

### DECLARATION OF THESIS AND COPYRIGHT

Author's Full Name : LYE JIUN YIN

Date of Birth : 09 MAY 1994

Title : DYNAMIC ANALYSIS OF ADOBE STRUCTURE WITH  
BILINEAR MATERIAL MODELLING

Academic Session : \_\_\_\_\_

I declare that this thesis is classified as:

- CONFIDENTIAL (Contains confidential information under the Official Secret Act 1997)\*
- RESTRICTED (Contains restricted information as specified by the organization where research was done)\*
- OPEN ACCESS I agree that my thesis to be published as online open access (Full Text)

I acknowledge that Universiti Malaysia Pahang reserves the following rights:

1. The Thesis is the Property of Universiti Malaysia Pahang
2. The Library of Universiti Malaysia Pahang has the right to make copies of the thesis for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified by:

\_\_\_\_\_  
(Student's Signature)

940509-14-6337

\_\_\_\_\_  
New IC/Passport Number

Date:

\_\_\_\_\_  
(Supervisor's Signature)

Dr. Gul Ahmed Jokhio

\_\_\_\_\_  
Name of Supervisor

Date:

NOTE : \* If the thesis is CONFIDENTIAL or RESTRICTED, please attach a thesis declaration letter.



## SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project report and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor Degree of Civil Engineering

---

(Supervisor's Signature)

Full Name : Dr. Gul Ahmed Jokhio

Position : Senior Lecturer

Date :

---

(Co-supervisor's Signature)

Full Name :

Position :

Date :



## **STUDENT'S DECLARATION**

I hereby declare that the work on this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

---

(Student's Signature)

Full Name : LYE JIUN YIN

ID Number : AA14193

Date :

DYNAMIC ANALYSIS OF  
ADOBE STRUCTURE WITH  
BILINEAR MATERIAL MODELLING

LYE JIUN YIN

Thesis submitted in fulfillment of the requirements  
for the award of the  
Bachelor Degree in Civil Engineering

Faculty of Civil Engineering and Earth Resources  
UNIVERSITI MALAYSIA PAHANG

JUNE 2018

## ACKNOWLEDGEMENTS

I would like to express my thankfulness to my supervisor Dr. Gul Ahmed Jokhio for his precious advices, guidance, motivation and moral support in making this study possible. I really appreciate his suggestion and encouragement to make me more clear and understand about this study. Without his guidance, my study will be hard to complete this study.

I sincerely warmly appreciated to all of the lecturers and staffs in Faculty of Civil Engineering and Earth Resources (FKASA), who help me during the university life and make me more understand about the civil engineering course especially for the course that related to my study. Furthermore, I would like to thanks to my final year project panels who give me the suggestions and advices during the presentation to make my study more clear and smooth. Furthermore, I also like to give many thanks to my course mates for their moral supports and cooperation during carry out this study. This marks my university life become more unforgettable and meaningful.

In addition, I am really like to give thousands of thanks to my parents. Their love, patience, sacrifices and opportunity to get the education start from small age until now. Without my parent guidance and support, I will not have a great chance to do this final year project. From final year project, I get the opportunity to expand my knowledge that related to this study via journal, internet and books.

Last but not least, I am extremely grateful to any individual who directly or indirectly contributes to my final year project. I appreciate their suggestion and moral supports to complete this study successfully.

## ABSTRAK

Struktur adobe sangat terdedah dalam beban dinamik terutamanya beban seismik. Sifat bahan adobe yang sesuai akan menyediakan kekuatan yang cukup untuk mengurangkan kerosakan bangunan adobe dan mengelakkan kematian serta menjimatkan kos penyelenggaraan. Dalam kajian ini, kaedah simulasi akan dijalankan dengan menggunakan perisian analisis unsur terhingga, ANSYS. Kajian simulasi ini akan membentangkan tentang kelakuan struktur untuk struktur model adobe yang mengalami beban dinamik. Tujuan kajian ini adalah untuk mengkaji kelakuan struktur adobe semasa mengalami beban seismik.

Dua jenis perbezaan sifat bahan adobe akan digunakan dalam kajian ini iaitu sifat-sifat tidak linear (bata adobe tanpa tetulang) dan sifat-sifat bilinear (bata adobe dengan tetulang wayar mesh). Dalam analisis ini, kelakuan struktur untuk dua bahan yang berbeza seperti pesongan, tekanan dan ketegangan akan dibandingkan. Ia dijangka mendapati bahawa apabila tetulang wayar mesh ditambahkan, kelakuan struktur adobe akan meningkatkan dengan ketara. Ia menunjukkan bahawa sifat-sifat bilinear (bata adobe dengan tetulang wayar mesh) akan menjadi lebih sesuai untuk terhadap beban seismik.

## **ABSTRACT**

Adobe structures are more vulnerable in dynamic loads especially for seismic loads. The proper material properties of the adobe bricks will provide the sufficient strength in order to minimize the damage of the adobe building and also prevent loss of human lives and save maintenance costs. In this study, the simulation method will be used by using finite element analysis software, ANSYS. This simulation study presents about structure behaviors of adobe model structures undergoes dynamic loads. The purpose of this study is to study the structure behaviour of adobe structures subjected to seismic load.

Two types of difference adobe material properties will be used in this study such as nonlinear properties (adobe brick without reinforcement) and bilinear properties (adobe brick with wire mesh reinforcement). In this analysis, the structure behaviour of two difference materials like deflection, stress and strain will be compared. It is expected to find that when wire mesh reinforcement is added, the structure behaviour of adobe improves significantly. It shows that the bilinear properties (adobe brick with wire mesh reinforcement) will be more suitable to against the seismic load.



## TABLE OF CONTENT

<b>DECLARATION</b>	
<b>TITLE PAGE</b>	
<b>ACKNOWLEDGEMENTS</b>	<b>1</b>
<b>ABSTRAK</b>	<b>2</b>
<b>ABSTRACT</b>	<b>3</b>
<b>TABLE OF CONTENT</b>	<b>4</b>
<b>LIST OF TABLES</b>	<b>7</b>
<b>LIST OF FIGURES</b>	<b>8</b>
<b>CHAPTER 1 INTRODUCTION</b>	<b>10</b>
1.1 BACKGROUND OF STUDY	10
1.2 PROBLEM STATEMENT	11
1.3 OBJECTIVE	11
1.4 SCOPE OF STUDY	12
1.5 EXPECTED OUTCOME	12
1.6 SIGNIFICANCE OF MY STUDY	12
<b>CHAPTER 2 LITERATURE REVIEWS</b>	<b>13</b>
2.1 INTRODUCTION	13
2.2 TYPE OF ADOBE	14
2.2.1 TRADITIONAL ADOBE	14
2.2.2 SEMI-STABILIZED ADOBE	15
2.2.3 FULLY STABILIZED ADOBE	15
2.2.4 PRESSED-ADOBE BRICKS	15

2.2.5	TERRONES	16
2.2.6	QUEMADO	16
2.3	APPLICATIONS OF ADOBE STRUCTURES	16
2.4	FINITE ELEMENT ANALYSIS (FEA)	19
2.4.1	TYPE OF ELEMENTS	20
2.4.2	TYPE OF ANALYSIS IN FINITE ELEMENT ANALYSIS	21
<b>2.4.2.1</b>	<b>STATIC ANALYSIS</b>	<b>22</b>
<b>2.4.2.2</b>	<b>DYNAMIC ANALYSIS</b>	<b>23</b>
2.5	FINITE ELEMENT ANALYSIS OF ADOBE	24
2.6	ANSYS & CIVILFEM	26
<b>CHAPTER 3 METHODOLOGY</b>		<b>27</b>
3.1	INTRODUCTION	27
3.2	FLOW OF WORKS	28
3.3	PREPARATION OF MODELS	29
3.3.1	MODELLING 3D SOLID ADOBE STRUCTURE	29
3.3.2	ENTERING TITLE AND JOBNAME	29
3.3.3	ACTIVATING CIVILFEM	30
3.3.4	DEFINING ELEMENT TYPES	30
3.3.5	DEFINING MATERIAL PROPERTIES	31
3.3.6	CREATING THE MODEL	32
3.3.7	MESHING	33
3.4	SOLUTION PHASE	34
3.4.1	APPLYING CONSTRAINTS	34
3.4.2	SETUP ALL FORCES	35
3.5	ANALYSIS PHASE	35

3.5.1	MESHING ACCURACY	36
3.5.2	READ RESULTS	37
3.5.3	PLOT THE DEFORMED SHAPE	38
3.5.4	SEISMIC ANALYSIS	39
<b>CHAPTER 4 RESULTS AND DISCUSSION</b>		<b>41</b>
4.1	INTRODUCTION	41
4.2	DEFORMATION OF BOTH MODELS	41
4.3	STRESS OF BOTH MODELS	47
4.4	SEISMIC ANALYSIS OF BOTH MODELS	59
<b>CHAPTER 5 CONCLUSION AND RECOMMENDATION</b>		<b>63</b>
5.1	INTRODUCTION	63
5.2	CONCLUSION	63
5.3	RECOMMENDATION	64
<b>REFERENCES</b>		<b>65</b>

## LIST OF TABLES

Table 4-1: Elastic spectrum of reinforced adobe models	60
Table 4-2: Elastic spectrum of unreinforced adobe models	60
Table 4-3: Mode Response of reinforced adobe models	61
Table 4-4: Mode Response of unreinforced adobe models	61
Table 4-5: Average period, frequencies of both models	62

## LIST OF FIGURES

Figure 2-1: Great Mosque of Djenné	17
Figure 2-2: Pueblo de Tao in New Mexico	18
Figure 2-3: Shibam, Yemen's Ancient Skyscraper City	19
Figure 2-4: Example of 1D element (Rabindranath Andujar Moreno, 2011)	20
Figure 2-5: Example of 2D elements (Rabindranath Andujar Moreno, 2011)	21
Figure 2-6: 3D elements with cube shape by repeating mesh units (AFEM Chapter 8, 2017)	21
Figure 2-7: Relationship of the Linear Static analysis (ANSYS Training Manual, 2005)	22
Figure 2-8: Relationship of the Non-linear Static analysis (ANSYS Training Manual, 2005)	23
Figure 3-1: Flow Chart of Process of Completing Final Year Project	28
Figure 3-2: Enter Title	29
Figure 3-3: Enter Jobname	30
Figure 3-4: Activate CivilFEM	30
Figure 3-5: Select Element Types	31
Figure 3-6: Material Setup Option	31
Figure 3-7: Select Material	32
Figure 3-8: Modelling	32
Figure 3-9: Subtract the Modelling	33
Figure 3-10: Adobe Room Structures Modelling	33
Figure 3-11: Meshing Option	34
Figure 3-12: Apply U, ROT on Nodes	35
Figure 3-13: Displacement Vector Sum (USUM) for coarse size	36
Figure 3-14: Displacement Vector Sum (USUM) for fine size	37
Figure 3-15: Read result	38
Figure 3-16: Deformed Shape	38
Figure 3-17: Seismic Design Option	39
Figure 3-18: Define Spectrum	39
Figure 3-19: Define Modal Solution	40
Figure 4-1: Deformation shape of reinforced adobe models	42
Figure 4-2: Deformation shape of unreinforced adobe models	42
Figure 4-3: X-component displacement of reinforced adobe models	43
Figure 4-4 X-component displacement of unreinforced adobe models	43

Figure 4-5: Y-component displacement of reinforced adobe models	44
Figure 4-6: Y-component displacement of unreinforced adobe models	44
Figure 4-7: Z-component displacement of reinforced adobe models	45
Figure 4-8: Z-component displacement of unreinforced adobe models	45
Figure 4-9: Displacement vector sum of reinforced adobe models	46
Figure 4-10: Displacement vector sum of unreinforced adobe models	46
Figure 4-11: X- component stress of reinforced adobe models	48
Figure 4-12: X-component stress of unreinforced adobe models	48
Figure 4-13: Y-component stress of reinforced adobe models	49
Figure 4-14: Y-component stress of unreinforced adobe models	49
Figure 4-15: Z-component stress of reinforced adobe models	50
Figure 4-16: Z-component stress of unreinforced adobe models	50
Figure 4-17: XY shear stress of reinforced adobe models	51
Figure 4-18: XY shear stress of unreinforced adobe models	51
Figure 4-19: XZ shear stress of reinforced adobe models	52
Figure 4-20: XZ shear stress of unreinforced adobe models	52
Figure 4-21: YZ shear stress of reinforced adobe models	53
Figure 4-22: YZ shear stress of unreinforced adobe models	53
Figure 4-23: 1st principal stress of reinforced adobe models	54
Figure 4-24: 1st principal stress of unreinforced adobe models	54
Figure 4-25: 2nd principal stress of reinforced adobe models	55
Figure 4-26: 2nd principal stress of unreinforced adobe models	55
Figure 4-27: 3rd principal stress of reinforced adobe models	56
Figure 4-28: 3rd principal stress of unreinforced adobe models	56
Figure 4-29: Stress intensity of reinforced adobe models	57
Figure 4-30: Stress intensity of unreinforced adobe models	57
Figure 4-31: Von Mises stress of reinforced adobe models	58
Figure 4-32: Von Mises stress of unreinforced adobe models	58
Figure 4-33: Spectrum horizontal component of reinforced adobe models	59
Figure 4-34: Spectrum horizontal component unreinforced adobe models	59

## **CHAPTER 1**

### **INTRODUCTION**

#### **1.1 BACKGROUND OF STUDY**

Adobe is made of sun-dried earth bricks also known as dried mud bricks. Adobe is the earliest building material in use because it is easy to procure and the cost is cheaper. Nowadays, the adobe structures are widely used throughout the world especially in the Spanish region, South Asia, Central Asia, Middle East, Africa, Peru and East Europe.

The adobe material has brittle characteristic and it has higher compression strength compared to its tensile strength. There are a few advantages and disadvantages of using adobe bricks. First of all, adobe bricks are cost effective and environment friendly compared to concrete material. This is because concrete is mixed with cement which produces carbon dioxide that causes the greenhouse effect; adobe does not produce carbon dioxide since it is made from earth. Adobe materials have low energy usage compared to other materials. In addition, adobe bricks have high fire resistance, high durability, and high resistance to sound transmission. The main disadvantage of adobe bricks is that these materials are very weak against tensile stresses especially due to earthquake or seismic load. Furthermore, making adobe structure is time consuming and the labor cost is high. However, in some parts of the world where unemployment is high, this is considered an advantage as it creates more jobs. Adobe structures are not suitable for the regions that have excessive raining, this is because the adobe structures are easy to break when mixed with water.

The seismic load is the major issue for adobe structures especially in South Asia, Central Asia, Middle East, Africa, and East Europe. Therefore, the properties of adobe need to be improved to prevent this issue. In a recent study, it was found that adding wire mesh reinforcement changes the material model to bilinear. In this study, the

ANSYS software will be used to model the adobe structure with bilinear material modelling. After making the model, it will be subjected to seismic load in order to assess the behaviors of adobe structures.

## **1.2 PROBLEM STATEMENT**

In general, the adobe structures are built in the rural areas of these regions, which are Spain, Mexico, South Asia, Central Asia, Middle East, Africa, and East Europe. These buildings are more environment friendly compared to using concrete as building material.

There are some major downsides to adobe structures when subjected to seismic load. In this study, the structure behaviors of adobe against seismic load will be studied. Adobe structures are weak against seismic load, this is because adobe material has low strength compared to concrete, has brittle properties, and is weak in shear and tension. This can cause severe damage to the building and loss of residents' lives. In 2001, an earthquake occurred in the south of Peru which caused the death of 81 people, the destruction of almost 25,000 adobe houses and the damage of another 36,000 houses, with the result that more than 220,000 people were left without shelter. In the same year, an earthquake happened in El Salvador, which caused more than 200,000 adobe buildings to be severely damaged or collapsed, 1,100 people died under the rubble of these buildings, and over 1,000,000 people were made homeless (EERI/IAEE World Housing Encyclopedia , 2003).

## **1.3 OBJECTIVE**

- 1) To model the adobe structure behavior using bilinear material model.
- 2) To study the behaviors of adobe structure subjected to seismic load.



#### **1.4 SCOPE OF STUDY**

This study is based on analytical study which consists of modelling and simulation. The ANSYS software will be used in this study. The materials properties that will be used to model the adobe structures are linear, non-linear and bilinear. After designing the adobe structures, the same model will be subjected to static and dynamic analysis. Then, the results of different models will be compared with each other and with literature. In this study, two models with different material properties such as non-linear and bilinear with 3D solid element will be analysed. The analysis type that will be used in this study is dynamic time history analysis.

#### **1.5 EXPECTED OUTCOME**

The expected outcome of this study is to achieve adobe structure modelling with bilinear material properties and normal material properties. At the same time, we understand about the structure behaviors of different type of material properties of adobe structures modelling when withstand to seismic load. It is expected to find that when wire mesh reinforcement is added, the structure behavior of adobe improves significantly.

#### **1.6 SIGNIFICANCE OF MY STUDY**

The finding of this study will be helpful in understanding the behavior of adobe subjected to seismic load. This will also help improve the mechanical properties of adobe for stronger and efficient construction. This study is important because it will prevent the severe damage of residents' lives and building and also minimize the maintenance cost to the adobe structure.

## CHAPTER 2

### LITERATURE REVIEWS

#### 2.1 INTRODUCTION

Adobe is one of the building materials that has been used to build housing and other structures for thousands of years. Adobe bricks are made of earth with a high content of clay and straw. If produced manually, then the earth mix is cast in open moulds onto the ground and then left to dry out. The application in construction is simple, they are laid up into a wall using an earth mortar. Before drying out, the finished walls are smoothed down. Often a clay render is applied as a surface coating. (TheGreenJump, 2017). These structures are widely used in some countries like Spanish region, Mexico, South Asia, Central Asia, Middle East, Africa, and East Europe. The adobe structures are generally used in hot climates areas, and not in the equatorial regions, which always have heavy rainfall such as Malaysia, Singapore, Indonesia and so on. The adobe brick is widely used in worldwide, but adobe material is weak against the dynamic analysis.

Dynamic analysis is one of the analysis methods in the structural analysis. This analysis is the study of kinematics and kinetics. In generally, dynamic loads are varies with time very rapid compared to structure's natural frequency. The dynamic loads applied on objects as time or frequency function, it will induce time or frequency-varying response such as displacements, accelerations, forces, stresses-strains and so on. These time or frequency-varying characteristics make dynamic analysis more complicated and more realistic than static analysis. The dynamic analysis is depends on the different types of the material model.

Bilinear material is also knowns as bilinear isotropic hardening. This material has bilinear properties in the uniaxial stress-strain curve. When the materials was added the loads, the stress will increase until the maximum stress and when the material is

unloaded, it compresses elastically along the dashed line which means that the material will turn back to original shape. If this material is reloaded, the stress will increase back. It shows that there is elastic characteristic of the material or hardening the material. The plastic deformation will occur when the stress was exceeded the maximum stress of the material.

## **2.2 TYPE OF ADOBE**

Adobe building material is sun-dried brick or mud dried brick which widely used in the regions that have little rainfall. Adobe brick contains the soil components such as sand, silt, and clay mixed with water, as well as amount of gravel. After the adobe was mixed with water, the material can cast into the shape that we desired. It can be used as plaster and mortar between adobe bricks. In generally, straw was added into the adobe bricks to minimize the cracking of the adobe (Brown, P., & Clifton, J, 1978). Edward W. Smith (1982) states that adobe materials have six types that available in Mexico. The types of adobes that he mentions are traditional adobe, semi-stabilized, fully stabilized, Terrónes, pressed adobe, and burnt adobe (Quemado).

### **2.2.1 TRADITIONAL ADOBE**

Traditional adobe brick is also known as untreated adobes. It is made with mixture of clay, sand, and silt. In generally, straw will added into the brick to prevent the brick cracking. This type of brick can be found in village and cities in some area such as New Mexico, Middle East, Africa, and so on. One of the examples of traditional adobe structure is the multi-storied Taos Pueblo structure, which has been carefully maintained for over 900 years by the Taos Pueblo Indians. The other example is old traditional adobe architecture that found in the numerous Spanish mountain villages of New Mexico which include adobe structures that are over 300 years old. In many of these villages, the adobe was combined with logs in Jacal construction, or was used as mortar with native field stone in addition to the traditional sun-dried brick construction (Smith, 1982). The main disadvantage of traditional adobes is vulnerable to water. To avoid this issue happened, the adobe mud brick walls should be plastered periodically and the other solution is permanent cement stucco applied over a wire mesh.

### **2.2.2 SEMI-STABILIZED ADOBE**

Semi-stabilized adobe is a new classification of adobe which developed by large scale adobe producers. The preparation of semi-stabilized adobe brick is same way as the traditional adobe brick, the percentage of asphalt emulsion added into the traditional ingredients of adobe brick is approximately 2–4% asphalt emulsion by weight in the final product. The addition of a small amount of asphalt emulsion into the adobes will result this adobe bricks contains waterproof and can be used for grade-level bases courses. Tests will made on several samples obtained from the producers of semi-stabilized bricks, after that the result will show the considerable variation in percentages of water absorption, moisture content, and erosion characteristics. The reason of carry out this test is to make the semi-stabilized bricks meet the requirement of New Mexico State Building Code (Smith, 1982).

### **2.2.3 FULLY STABILIZED ADOBE**

Fully stabilized adobe brick is a water-resistant adobe which added about 6% to 12% of asphalt emulsion. This brick can be exposed to the elements with less danger of cracking or erosion. The production of fully stabilized adobe brick require no additional protection stabilized and can be left exposed without stucco. The production of fully stabilized adobe brick is very low because most walls are stuccoed with water-resistant plaster, and the additional waterproofing agent adds extra cost without returning added benefits. (Agnew et al.,1990). The fully stabilized adobe brick have some advantages, which are this bricks is water proof brick will have the extra protection against the water, have higher of fire resistance, and also higher durability which can resist the erosion and sand storm in desert area.

### **2.2.4 PRESSED-ADOBE BRICKS**

Pressed-adobe bricks are produced which used traditional or stabilized adobe materials. This brick contain higher content of clay than standard adobes about 30 to 35 percent and are made with a damp, low-moisture mixture. The soil mix is pressed into a dense adobe brick of varying size, using either a hydraulically operated power machine or a hand-operated press. The machine-made pressed-adobe bricks investigated were all produced in the standard 10 x 4 x 14-inch size. The hand-operated CINVA-Ram press produced a 33/4 x 5½ x 11½-inch-size brick. Both traditional (untreated) and stabilized

(treated) pressed-adobe bricks were manufactured; however, production of all types of pressed adobes was very limited with an estimated total of only 15,000 bricks manufactured state wide in 1980. Of this total, the majority of the pressed adobes produced were used by the adobe producers in personal construction projects (Smith, 1982).

### **2.2.5 TERRONES**

Terrónes is one of the adobe bricks that widely used in current century. This Spanish word, terrón means a flat clod of earth. The terrónes are widely used in the Albuquerque Basin area of New Mexico and particularly at the Pueblo of Isleta. The terrónes usually measure 7 x 7 x 14 or 4 x 7 x 14 inches and are cut during the spring of each year from the sod areas of the floodplains of the Rio Grande. Both tribal pasture land and individual-ownership lands have areas along the river bottom where the bricks are cut. An ordinary garden spade with a blade that has been flattened and cut down to measure 7 x 8 inches is used to cut the sod. Usually two or more individuals will be engaged in the cutting, stacking, and final transportation of the terrónes to the construction site (Smith, 1982).

### **2.2.6 QUEMADO**

Quemado adobe is also known as burnt adobe which is a kind of traditional sun-dried adobe brick or using fire to burn the adobe brick. The producers normally will use wood, kerosene, old tires to burn the bricks in a stacked-brick oven that is built to allow air circulation within the kiln. Usually firewood is fed through the small doors at each end of the kiln with smoke escaping through the smoke holes at the top (Smith, 1982).

## **2.3 APPLICATIONS OF ADOBE STRUCTURES**

Adobe structures are widely used in worldwide due to the low cost of construction and environmental friendly. There are some of the famous buildings that made by adobe brick in the world. A few examples are provided below.

First of all, Great Mosque of Djenné is one of the wonderful and unique religious buildings in Africa. This building was founded between 800 and 1250 C.E., and it is become a great center of commerce, education, and Islam, which had been practiced from the beginning of the 13th century. After that, the Great Mosque became one of the most important buildings in Mali town because it became a political symbol for local residents and for colonial powers like the French who took control of Mali in 1892. Over the centuries, the Great Mosque has become the epicenter of the religious and cultural life of Mali, and the community of Djenné. (Dainese, E., n.d.).



**Figure 2-1:** Great Mosque of Djenné

The other place that has famous adobe architecture is Taos Pueblo which located at New Mexico in USA. These buildings were built by Pueblo Indian during late 13th and early 14th centuries. They lived in this unique multistoried adobe homes and ceremonial structure. Nowadays, the Taos Pueblo is become one of the places of tourists and heritage of the American Southwest, these architectures was reflected the cultural interactions between the American Indians and the Spanish. In 13th and early 14th centuries, Taos Pueblo was a main center of trade and communications between American Indian tribes, the Indians and the Spanish. This ancient pueblo is an example of traditional adobe architecture that has preserved its original appearance through the efforts of the community's resistance to modernization and outside influence.



**Figure 2-2:** Pueblo de Taos in New Mexico

Shibam is the first skyscrapers which made of adobe brick in Yemen. This building was surrounded by palm groves, and flanked by the steep cliffs leading up to the Yemeni highland on both sides, the city of 2,000 inhabitants hardly seems impressive. These buildings were built almost five centuries ago, and now have preserved until now. It is a handful of high-rise residential buildings, not so much different from the Soviet-style blocks found across the Arab world. The Shibam city become one of the few to be designated a UNESCO World Heritage site in its entirety, appears to rise from the plains. Its 500 houses reach an astounding 100 feet in height, almost as high as Chicago's first skyscrapers. Perhaps most remarkable of all is the fact that the city was built using nothing but mud. (Arthur. B, 2015).

The city is surrounded by fertile land employed for agriculture, using an integrated urban system for the simultaneous generation of food and building materials. After crops are harvested from the surrounding land, soil is collected for construction inside the walled city and construction is a continuous process, with the towers requiring regular maintenance with fresh coats of adobe mud. Shibam is an architecture that harmonizes with a population deeply devoted to traditional Muslim culture. Early incarnations of Islamic architecture can be noted in the fenestration on the higher levels of the structures while the ground levels were dictated by security, creating a fortress-like defense system to protect the affluent residents inside. (Finn, M. , 2015).



**Figure 2-3:** Shibam, Yemen's Ancient Skyscraper City

## **2.4 FINITE ELEMENT ANALYSIS (FEA)**

Finite element analysis is type of a numerical method. This method is used to solve the engineering complex structures and mathematical physics. Furthermore, this method can solve some problems that analytical method cannot be solved. One of the examples of FEA is find the stresses and strains of engineering components such as beam, truss, bar element and so on under load. Through FEA, we can identify the structural behaviors of the structures elements. FEA is now applied to problems involving a wide range of phenomena, including vibrations, heat conduction, fluid mechanics and electrostatics, and a wide range of material properties, such as linear-elastic (Hookean) behaviour and behaviour involving deviation from Hooke's law (for example, plasticity or rubber-elasticity). (ITTI Update, 2008)

Nowadays, the computer hardware technology and slashing of cost of computers have boosted this method, since the computer is the basic need for the application of this method. A number of famous brand of finite element analysis software are STAAD-PRO, ABACUS, NASTRAN, CIVILFEM and ANSYS. These packages one can solve several complex structures. The finite element analysis originated as a method of stress analysis in the design of aircrafts. It started as an extension of matrix method of structural analysis. This method is used not only for the analysis in solid mechanics, now can even analyse the fluid flow, heat transfer, electric and magnetic fields and many others. Civil engineers use this method extensively for the analysis of structures like beams, space frames, plates, shells, folded plates, foundations etc. This method also

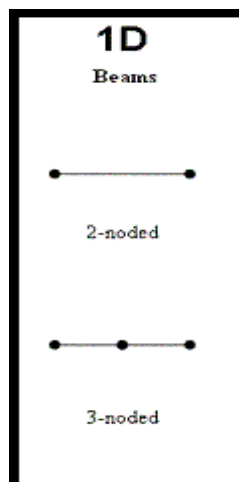


used extensively for the analysis and design of ships, aircrafts, space crafts, electric motors and heat engines (S. S. Bhavikatti, 2005).

### 2.4.1 TYPE OF ELEMENTS

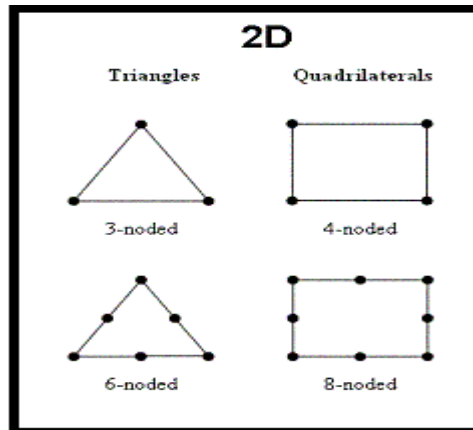
In finite element analysis (FEA), the element is defines as the basic building block to model the building. The element is a mathematical relation that defines how the nodes will define the degree of freedoms. In FEA, these elements are developed independently and vary from one finite element (FE) software to another. The elements have consists three groups which are one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) elements (C M Wai et al, 2013).

One-dimensional (1D) elements are knowns as line element. 1D element is the simple element compared to 2D and 3D element in finite element analysis. The line element can be in form of straight line or curve. The examples of the 1 D element are bar, truss, frame and beam element.



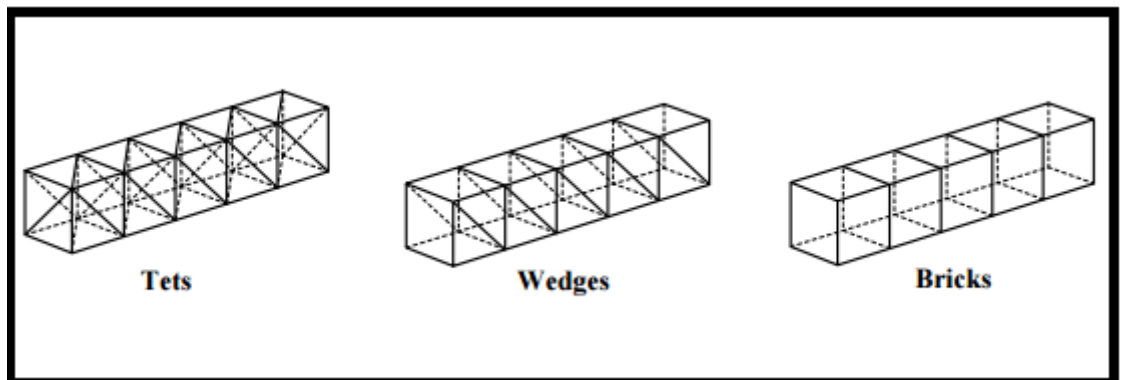
**Figure 2-4:** Example of 1D element (Rabindranath Andujar Moreno, 2011)

Two-dimensional (2D) elements are area or plane elements either with triangle, quadrilateral or polygon. There are the few examples of 2D elements are plane 3-node triangular element, 6-node triangular element, membrane element, shell element, and 2D planar. In plane element, the plane stress and plain strain are often used to solve 2D elasticity problems.



**Figure 2-5:** Example of 2D elements (Rabindranath Andujar Moreno, 2011)

3D elements are known as solid elements. This element is more difficult compared to other elements. There are three standard geometries: the tetrahedron, the wedge, and the hexahedron or “brick”. These have 4, 6 and 8 corners respectively with three faces meet at each corner.



**Figure 2-6:** 3D elements with cube shape by repeating mesh units (AFEM Chapter 8, 2017)

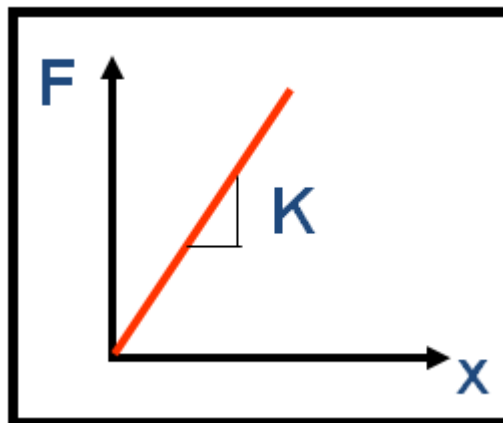
#### 2.4.2 TYPE OF ANALYSIS IN FINITE ELEMENT ANALYSIS

The Finite Element Analysis consists of static analysis and dynamic analysis. The static analysis does not depend on time change, whereas dynamic analysis is variable in time alteration, as known as time-based simulation.

### 2.4.2.1 STATIC ANALYSIS

**Static analysis** is the condition when yield strength of material is greater than generated stress. For example, if the frame by frame in proportion with time, any deformation of model as calculation result that performed previous frame are neglected in the next frame. This analysis is called small deformation analysis, the stress works in elastic area of material in this analysis was applied. The static analysis widely used to verify whether current design meet infinite life time work condition or not, of course combining the stress calculation result with theory of failure that include safety factor in it. (Yannu, F. , 2009). The static analysis has divided into two different type of analysis: linear static analysis and non-linear static analysis.

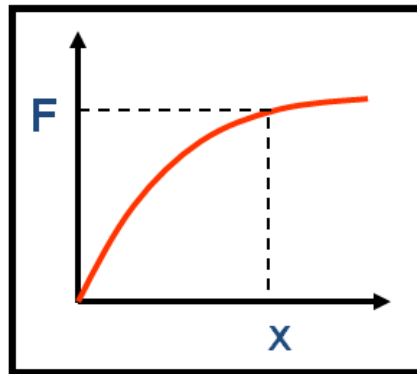
The linear static analysis is an analysis where a linear relation holds between applied forces and displacements. This is applicable to structural problems where stresses remain in the linear elastic of the used material. In this analysis, stiffness matrix  $[K]$  is constant, and the solving process is short compared to nonlinear analysis on the same model. (Femto Engineering, 2017).



**Figure 2-7:** Relationship of the Linear Static analysis (ANSYS Training Manual, 2005)

The non-linear static analysis is an analysis where a nonlinear relation holds between applied forces and displacements. Nonlinear effects can originate from geometrical nonlinearity's (large deformations), material nonlinearity's (elasto-plastic

material), and contact. These effects result in a stiffness matrix which is not constant during the load application. This is opposed to the linear static analysis, where the stiffness matrix is constant. As a result, a different method is required to solve the nonlinear analysis. (Femto Engineering, 2017). In non-linear static analysis, the stiffness matrix  $[K]$  is dependent on the displacement  $\{x\}$ .



**Figure 2-8:** Relationship of the Non-linear Static analysis (ANSYS Training Manual, 2005)

#### 2.4.2.2 DYNAMIC ANALYSIS

Dynamic analysis is the condition when the generated stresses from external load exceed yield strength. In dynamic analysis, deformation of the models will be analyzed since the exposed loads are time –dependent, so the shape transformations are considered. This analysis is also known as large deformation analysis. This method is useful to identify the behavior of models when applied in overload condition, such as collision analysis, crack propagation and etc. (Yannu, F. , 2009). There are few examples of dynamic analysis which are Spectral Response Analysis, Frequency Response Analysis, Time History Analysis and so on. The dynamic analysis has divided into linear dynamic analysis and non-linear dynamic analysis.

In linear dynamic analysis, the applied loads are time-dependent. Linear dynamic analysis is commonly used in the profession especially in design office. This is

because this analysis is more available in computer software compared to non-linear dynamic analysis. The external loads applied can be deterministic (periodic, non-periodic), or non-deterministic which means that cannot be predicted precisely but can be described statistically. For linear dynamic analysis, the mass, stiffness, and damping matrices do not vary with time.

In generally, the non-linear dynamic analysis will be used when nonlinearity like stiffness and damping nonlinearities of the model exists. The example of nonlinear dynamic analysis is Time History Analysis. Non-linear dynamic analysis attempts to fully represent the seismic response of buildings without any of these major simplifying assumptions. It is concluded that this analysis is the only appropriate method for verifying the performance of the certain structures, and that the traditional reasons preventing its widespread adoption are all but invalid. (Chamber & Kelly, 2004)

## **2.5 FINITE ELEMENT ANALYSIS OF ADOBE**

The finite element models of different representations for the adobe masonry walls such as the openings' lintels, the roof and the timber loading-beam were developed in Abacus. All parts were discretized using 8-noded 3D linear brick elements (C3D8). The dimension of for masonry elements were  $40 \pm 4$  mm long. In total, the mesh generated consisted of 47,808 elements and 68,139 nodes, resulting in 169,515 degrees of freedom. (Illampas, R., et al. , 2014)

The models were performed well in the deformation the structure. The maximum lateral displacement occurs at the rear wall, at the level where loading was applied. The displacements along the height of the facade display a linear increase towards the top wall. The backwards movement was predicted at the rear central part of the side wall is verified by experimental measurements and attributed to out-of-plane bending and subsequent torsion of this section.

The time history analysis of the relative out-of-plane displacement recorded at the rear wall's central upper section. Relative displacement data were analyzed by subtracting the translation of the rear wall's central base node along the y-axis from the

total out-of-plane displacement of the corresponding nodal point at the top of the wall. Based on the results, the maximum deflection induced is about 11.4 mm at 4.9 s when the seismic acceleration was reached its peak value. From this point onwards, the rear wall oscillates around a new equilibrium position at approximately  $-1.5$  mm, indicating residual inelastic deformation. (Illampas, R., et al. , 2014)

Based on research the Islam &Watanabe (2004), they developed two models of adobe structure (model M1 and model M2) for mid-height and the top of the model to compare the time history for displacement.

For model M-1, the height of the model is 1.0 m, and 10 blocks in the model. Each block has the dimension of  $0.25\text{ m} \times 0.50\text{ m} \times 0.10\text{ m}$ , the mortar was applied in between two blocks. Mortar joint has been neglected while modeling the shaking model. 20-nodded solid elements have been used to incorporate the blocks. For model M-2, the procedure of develop the model and size of model are same as model M-1. The joints were added in both the horizontal and vertical directions, but the joints have been neglected while modeling the shaking model. These two models have undergoes the shaking test to identify the displacement time history analysis at the mid-height and for the top of the model. In this test, the numerical simulation has been performed for the resonance frequency that has been observed in the shaking test. The first predominant frequency that was observed in the shaking test of this model is 5.0 Hz.

The relative displacement time histories of the model M-1 by FEM and that from shaking tests are compared for mid-height and the top of the model. It is show that the coincidence of the displacement time histories for finite element and the experiment is very good in respect of both the amplitude and phase angle. In conclusion, the ELM seismic behaviour that is observed in the shaking test can be well simulated.

For the relative displacement time histories of the model M-2 by FEM and that from shaking tests are compared at the mid-height and for the top of the model. It is seen that the coincidence of the displacement time histories for finite element and the experiment is very good in respect of both the amplitude and phase angle. Therefore, it

can be concluded that using the ELM seismic behaviour that observed in the shaking test can be well simulated by FEM.

## **2.6 ANSYS & CIVILFEM**

Nowadays, the finite element analysis is required to use computer in order to solve the complicated engineering problem especially in structural analysis. There are some famous finite element analysis softwares that commonly used to solve are LUSAS, ANSYS, ADINA, ABACUS, ZUES NL etc. In this study, the ANSYS & CivilFEM will be used.

In generally, CivilFEM is the software under ANSYS. ANSYS and CivilFEM is one of the most advanced, comprehensive and reputable finite element analysis and design software package available for structural engineering projects. CivilFEM performs the best customization of ANSYS, which combine the state of the art general purpose structural analysis features of ANSYS with high-end civil engineering-specific structural analysis capabilities. This will make the ANSYS become more unique and powerful for a wide range of civil engineering projects such as bridges, singular buildings, foundations, seismic structures, offshore structures, etc (Sir Robert McAlpine, n.d.).

CivilFEM can solve all types of advanced finite element analysis such as dynamic, static, linear and non-linear analysis. Besides that, the user can check the model based on international Codes and Standards (AISC, LRFD, EC2, EC3, etc.) for Reinforce Concrete, Structural Steel, seismic analysis, and so on. CivilFEM has a modular design composed by CivilFEM Intro and specialized modules which relate to specific civil engineering needs such as the bridges and civil non-linearities module, the advanced Prestressed concrete module and the geotechnical module that can be optionally added to CivilFEM Intro. At the same time, CivilFEM Multidiscipline includes all these specialized modules developed for CivilFEM (Intro, Geotechnical, Bridges and Civil non-linearities, and Advanced Prestressed Reinforced Concrete Modules), providing users with a complete solution that will suit all their civil engineering needs (C., Rodriguez. (n.d.)).

## CHAPTER 3

### METHODOLOGY

#### 3.1 INTRODUCTION

In this study, there are three different material properties of adobe materials to be tested which are non-linear (without any reinforcement) and bilinear (reinforce with wire mesh). The purpose of this study is to structural behavior of the two different material properties of adobe models such as deformation (strain) , stress (like von-mises stress, stress intensity and so on).

In this study, the simulation method will be carried out by using ANSYS and CIVILFEM software. The testing method and explanation of the method will be discussed in this chapter.

The methodology of this study is a guideline to achieve the objective of this study.

There are some steps are taken to conduct this study:

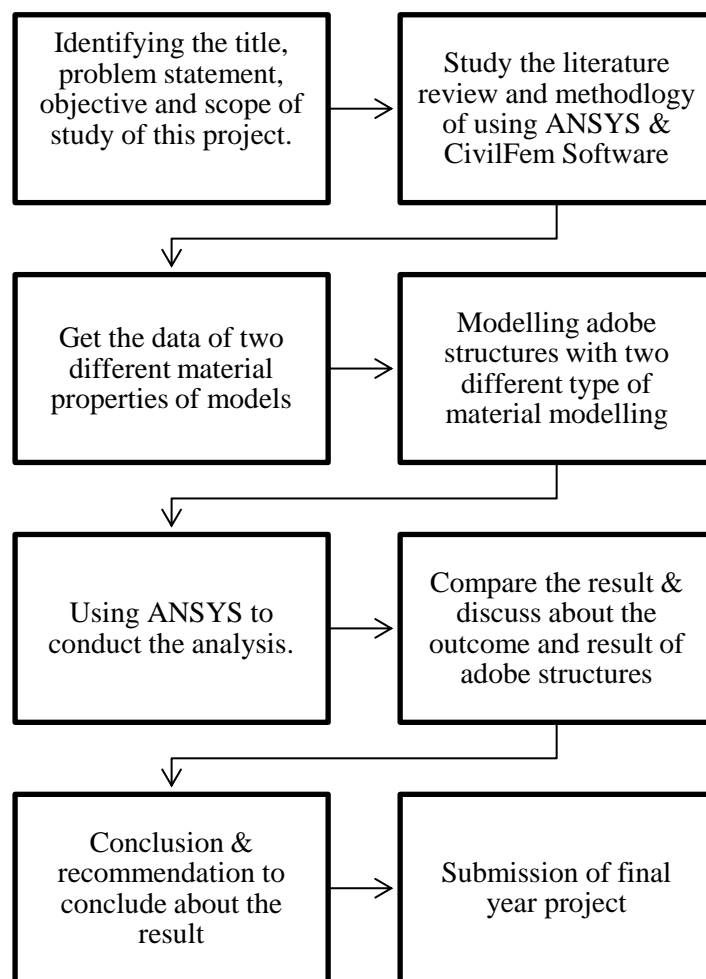
- (i) The data of the material properties of adobes with two different types are collected.
- (ii) The 3- Dimension Solid of two models (a room) will be generated.
- (iii) The data of the load and material properties of different adobes will be input into the software. After that, run the seismic analysis.
- (iv) The process of simulation was analysed by using ANSYS + CivilFEM software.



- (v) The meshing accuracy of the model will be checked.
- (vi) The structural behavior of two models are compared.

### 3.2 FLOW OF WORKS

The following flow chart below is showed to complete the entire study.



**Figure 3-1:** Flow Chart of Process of Completing Final Year Project

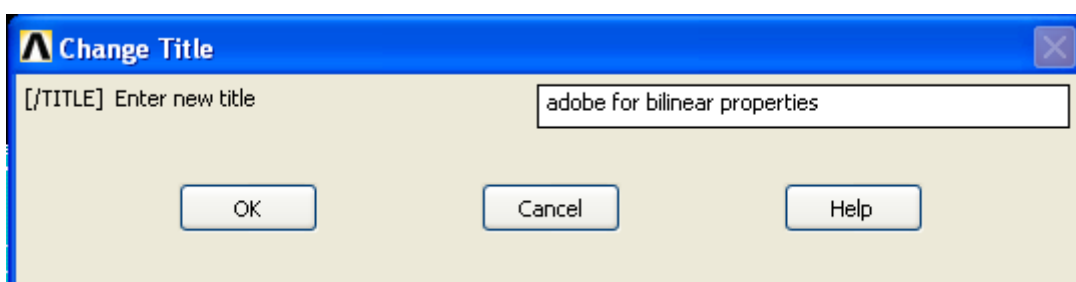
### 3.3 PREPARATION OF MODELS

#### 3.3.1 MODELLING 3D SOLID ADOBE STRUCTURE

ANSYS & CivilFEM software can be used to design engineering structural model. The 3D Solid adobe structure with three different types of material properties will be modelled in this study. Next, the coordinate for each points of structure are inserted as key points in the software to create the shape of the model of adobe structure in 3D form. After that, the key points are to be joined together to form the structure shape in 3D. Finally, this model will be analyzed to get the result of deflection, stress and strain.

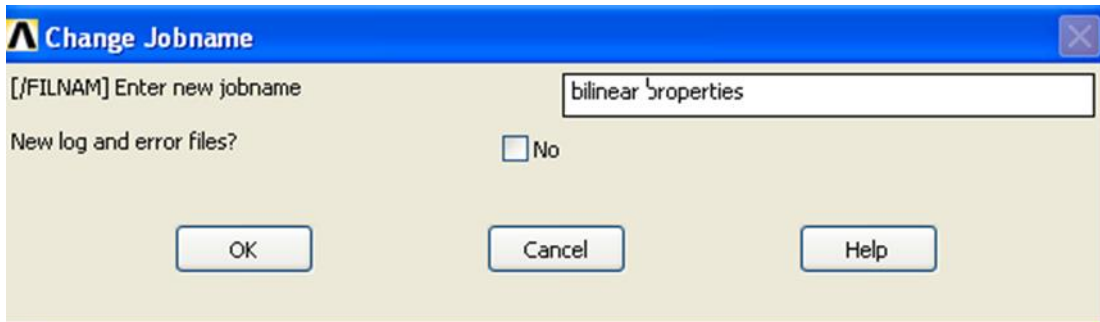
#### 3.3.2 ENTERING TITLE AND JOBNAME

Firstly, a title for the study shall be named by following the steps. Select “File” from the Utility Menu and click “Change Title”. Create a title for the study as “Adobe structure for linear properties”, and then click “OK” as shown in figure 1 below. After that, the title will display at the bottom left of window. For the other two models, the title names are “Adobe structure for non-linear properties” and “Adobe structure for bilinear properties”.



**Figure 3-2:** Enter Title

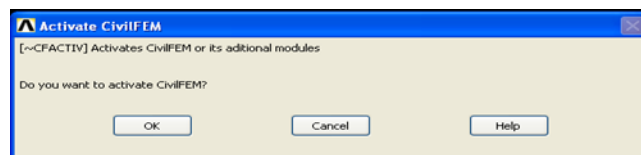
Next, the Jobname for this study shall be named as well so that can know the database name and become easy to find for next time. For this study, the jobname



**Figure 3-3: Enter Jobname**

### 3.3.3 ACTIVATING CIVILFEM

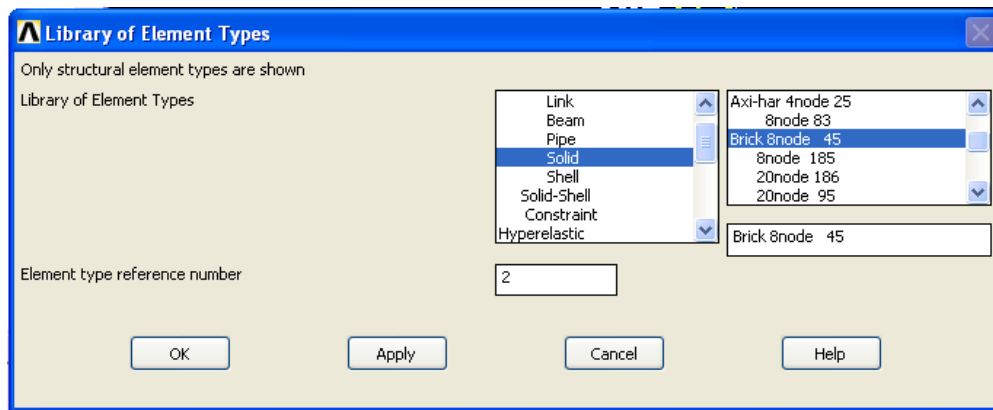
ANSYS CivilFEM was activated because CivilFEM will improve dramatically the efficiency of the structural design and analysis process. This will analysed the adobe structure with come out the result such as deflection, stress and strain. On the left side screen, we can see the ANSYS Main Menu, then we should click CivilFEM and then the click “OK”to activate CivilFEM.



**Figure 3-4: Activate CivilFEM**

### 3.3.4 DEFINING ELEMENT TYPES

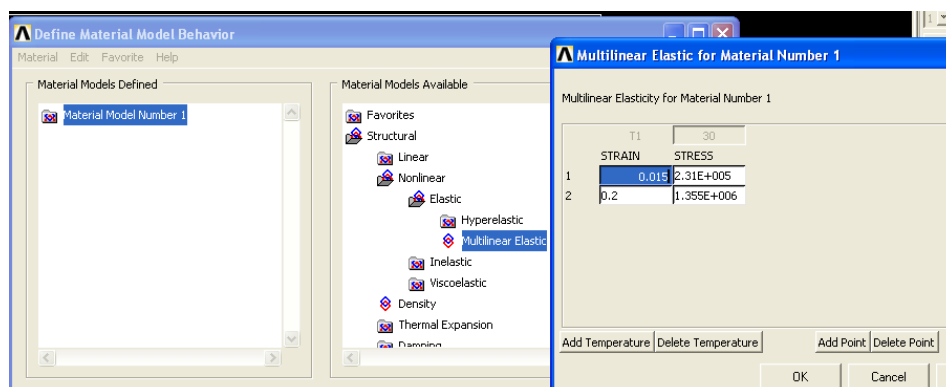
To defined element types for each model, choose “Civil Preprocessor” at ANSYS Main Menu and then click it. After that, click “Element type” and select “solid”. In this study, the element SOLID 45 (known as brick 8 node 45) will be used.



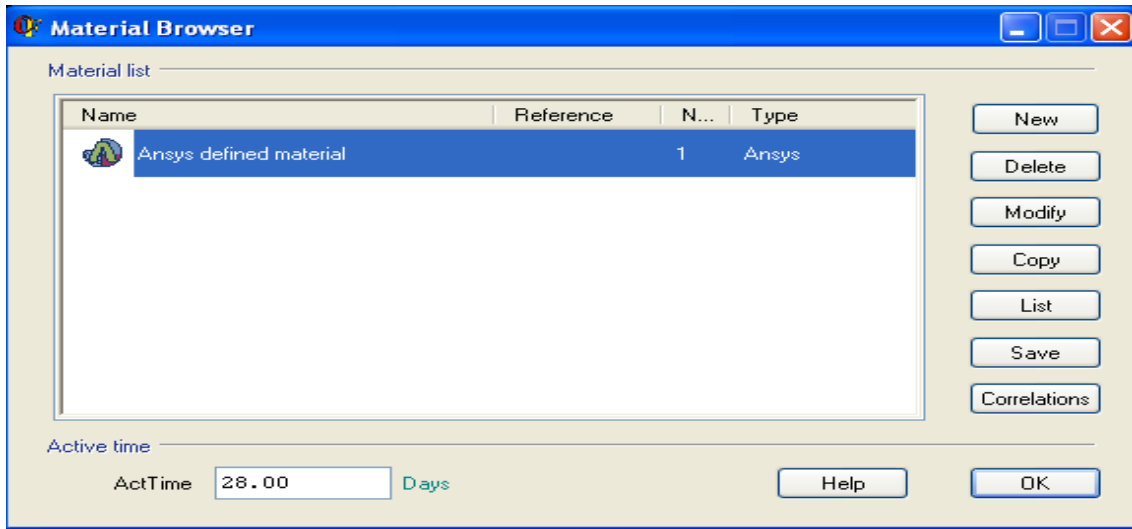
**Figure 3-5: Select Element Types**

### 3.3.5 DEFINING MATERIAL PROPERTIES

To define the material of adobe structure, click “Preprocessor” on ANSYS main menu, then click “Material models”. Then select “Nonlinear” follow by “Elastic”, “Hyperelastic” and “Multilinear Elastic” then key in the stress and strain of the non-linear and bilinear material properties. For bilinear properties, the young modulus is 15.42 MPa for bilinear properties and 14.65 MPa for non-linear properties. The data of non-linear and bilinear material properties get from the experimental data of previous research. The Poisson's ratio for both models is 0.15 and for the density of adobe materials for both models are 1540 kg/m<sup>3</sup> (Olukoya Obafemi, A. and Kurt, S, 2016). After that, go to “Civil Preprocessor”, it shows the ANSYS defined material in Material Browser. The ANSYS defined material is the materials that based on the data. The properties of elements were decided and then click “OK”.



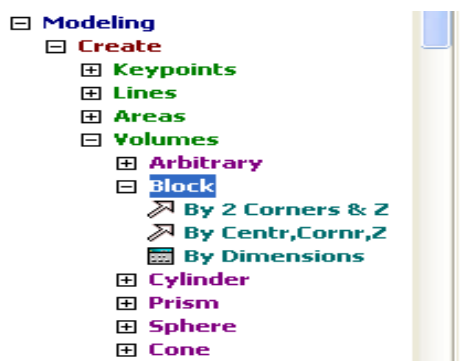
**Figure 3-6: Material Setup Option**



**Figure 3-7: Select Material**

### 3.3.6 CREATING THE MODEL

To make the models, we need to create the key points. Firstly, choose “Modelling” from Preprocessor which placed at the ANSYS main menu, then click on “Create” follow with “Volume”, “Block” and “By dimensions”. The dimension of the adobe structures (one room size) is about 4m for length, 4m for width and 3 m for height (4m x4m x3m). In this study, the same dimensions of the structures will be used in two different material properties. The thickness of the wall for the structure is 0.2m. Then need to create the second block in order to cut the volume inside and become hollow. Room usually empty inside, and with only wall surrounded.

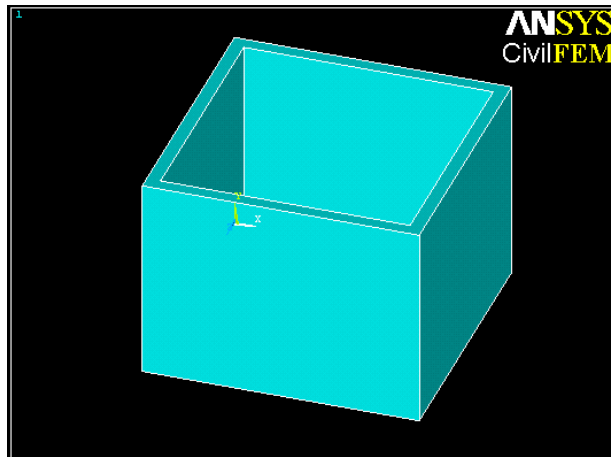


**Figure 3-8: Modelling**

After creating the models, select the “Operate” follow with “Booleans”, “Subtract” and “Volume”. In next step, select the bigger block and then next is smaller block (large size block-smaller size block), the adobe room is created.

- [-] Modeling
  - [+] Create
  - [-] Operate
    - [+] Extrude
    - [+] Extend Line
    - [-] Booleans
      - [+] Intersect
      - [+] Add
      - [+] Subtract
      - [+] Divide
      - [+] Glue
      - [+] Overlap
      - [+] Partition
      - [+] Settings
      - [+] Show Degeneracy
    - [+] Scale

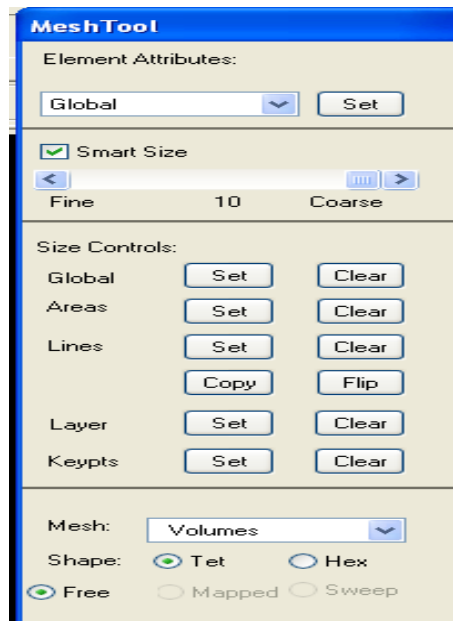
**Figure 3-9:** Subtract the Modelling



**Figure 3-10:** Adobe Room Structures Modelling

### 3.3.7 MESHING

To mesh the model, select in Main Menu bar, choose “Preprocessor”, “Meshing”, “Mesh Tool”. In Element Attribute, pick on Global Set, next select the smart size and set the size as 10 (Coarse mesh). Then click “Mesh”, “Pick all”, and “Close”.



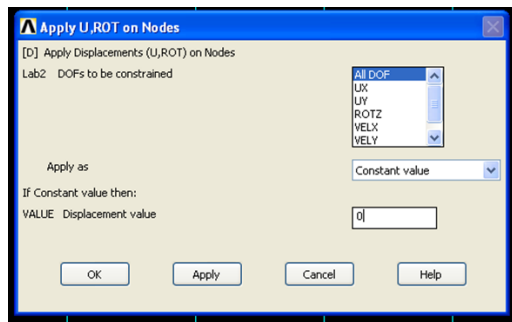
**Figure 3-11: Meshing Option**

### 3.4 SOLUTION PHASE

This phase is very important to analyse the structure before generating the results at the post processing phase. This phase is where the structure will be assigned forces and setting of constraint. After that, solve the analysis.

#### 3.4.1 APPLYING CONSTRAINTS

Before running the analysis of the models, we need to set the supports likes fixed support, pinned support, or roller support to some areas, so that the computer analysis can carry out successfully. For this model, we choose all fixed support at the bottom areas because fixed support more stable and strong compare to other supports. From Main Menu bar, select “Solution”, “Define Loads”, “Apply”, “Structural”, “Displacement” and next select “Area”. Pick the bottom areas of the structures and choose “All DOF” for the DOFs to be constrained and enter “0” for the displacement value.



**Figure 3-12:** Apply U, ROT on Nodes

### 3.4.2 SETUP ALL FORCES

In this study, the vertical loads from the roof on the wall are applied to the model to make this software analysed the structure. Firstly, click “solution” from main menu, click “defines load”, click “apply”, click “structural” and click “pressure” on the top wall area. The value key in in the “pressure” is -300kN (design load, negative means downward direction), and then the uniform distribution load (UDL) was created.

After all the nodes, elements, forces, supports and loads were defined, we can analyse the structure and get the result by click “Solution” from main menu and click “Solve” then click “Current LS” to analyse the structure automatically. After that, wait for analysis done and the word “Solution is done!” will appear on your screen. This stage is very important to check the result of structure after running the analysis. This cannot be done when the solution haven’t completed.

### 3.5 ANALYSIS PHASE

In this phase, general results such as deformation, stress-strain, component stresses, principal stresses and so on will be obtained in Postprocessing. After insert the materials properties data or information about the force, constraints etc., the meshing accuracy need to be proceed before get the general result.



### 3.5.1 MESHING ACCURACY

The meshing accuracy of the models is an important step to make sure the models are more accuracy and then the result will be more precise. The model will be mesh continuously until the relative percent difference in the results of the finer and the coarser mesh is less than 5%. In this step, the models with bilinear properties of adobe structure will be used. The tested load will use about 2600 N, this is because larger load will show the error.

Firstly, the models will undergo coarser mesh (10). After input the loading on the adobe room model, then run the solution by click the solve button in solution. After that, general results like nodal solution at node 1 will be obtained in General Postproc. The nodal solution consist degree of freedom (DOF) solution like nodal displacements, temperatures, and pressures. In nodal solution, the displacement vector sum (USUM) in node 3 will be used to check the meshing accuracy. The USUM for node 3 with coarser mesh (mesh size 10) is  $0.51691 \times 10^{-3}$ . For finer mesh (mesh size 1), the displacement vector sum (USUM) in node 3 finer mesh (mesh size 1) is  $0.51636 \times 10^{-3}$ .

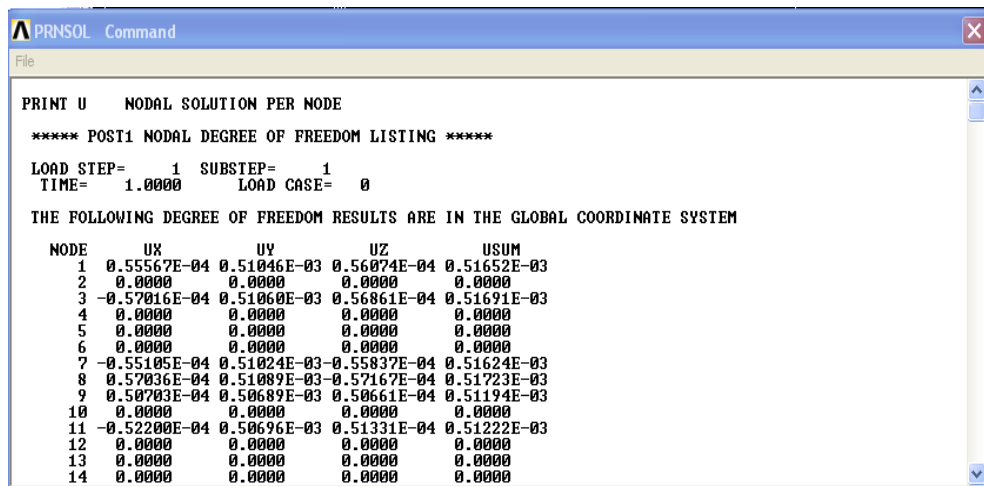


Figure 3-13: Displacement Vector Sum (USUM) for coarse size

```

PRNSOL Command
File
PRINT U      NODAL SOLUTION PER NODE
***** POST1 NODAL DEGREE OF FREEDOM LISTING *****
LOAD STEP=   1  SUBSTEP=   1
TIME=   1.0000  LOAD CASE=   0
THE FOLLOWING DEGREE OF FREEDOM RESULTS ARE IN THE GLOBAL COORDINATE SYSTEM

```

NODE	UX	UY	UZ	USUM
1	0.54759E-04	0.50980E-03	0.54802E-04	0.51565E-03
2	0.0000	0.0000	0.0000	0.0000
3	-0.55789E-04	0.51032E-03	0.55573E-04	0.51636E-03
4	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0000	0.0000
7	-0.55846E-04	0.51020E-03	-0.55385E-04	0.51623E-03
8	0.54884E-04	0.50999E-03	-0.55782E-04	0.51596E-03
9	0.49894E-04	0.50717E-03	0.49554E-04	0.51202E-03
10	0.0000	0.0000	0.0000	0.0000
11	-0.50800E-04	0.50755E-03	0.50505E-04	0.51258E-03
12	0.0000	0.0000	0.0000	0.0000
13	0.0000	0.0000	0.0000	0.0000
14	0.0000	0.0000	0.0000	0.0000

**Figure 3-14:** Displacement Vector Sum (USUM) for fine size

Therefore, the relative percent difference in the results between the coarse and fine mesh

$$\begin{aligned}
 & \frac{|Fine - Coarse|}{Coarse} \times 100\% \\
 &= \frac{|0.51636 \times 10^{-3} - 0.51691 \times 10^{-3}|}{0.51691 \times 10^{-3}} \times 100\% \\
 &= 0.11\%
 \end{aligned}$$

Since the difference is less than 5%, the any mesh size is suitable to be used in this study. In order to get the result more accuracy, smaller mesh size will be used. Therefore, use mesh size of 5 for each models to run the analysis.

### 3.5.2 READ RESULTS

After running the analysis, click on Main Menu, next select “Postprocessor” followed by “List Results”, then select the “nodal solution”. Then, the result such as stress, deflection etc. will be obtained. These results of both models will be compared through taking one of the nodes of the models, for example take the result of stress and deformation in node 3 (located at one of the corner of the models) , then compare the number.

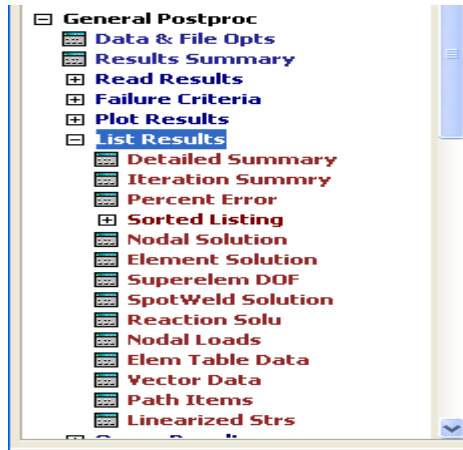


Figure 3-15: Read result

### 3.5.3 PLOT THE DEFORMED SHAPE

In the Main Menu Bar, select “General Postproc”, choose “Plot Results” and lastly “Deformed Shape”. When the window below pop up, select “Def + undeformed” and click “OK”.

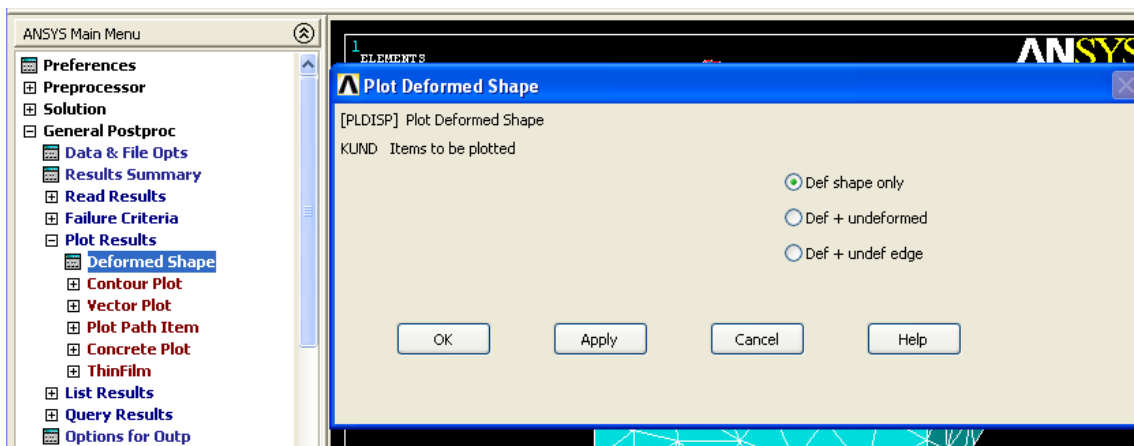


Figure 3-16: Deformed Shape

### 3.5.4 SEISMIC ANALYSIS

The seismic analysis of both models will be compared. To start this analysis, click “Seismic Design”, followed by “Define Spectra” and “By code”. Next, the define spectrum option will appear, this analysis will follow the Eurocode 8. In the define spectrum option, the design ground acceleration is 0.70g (violent perceived shaking and heavy potential damage), and the damping factor is 0.05, spectrum shape selected as 1 (which is high and moderate seismicity regions,  $M_s > 5.5$ ), and subsoil class is type A (rock site). This spectrum analysis is selected as elastic spectrum analysis.

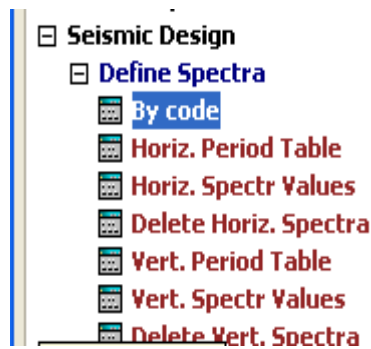


Figure 3-17: Seismic Design Option

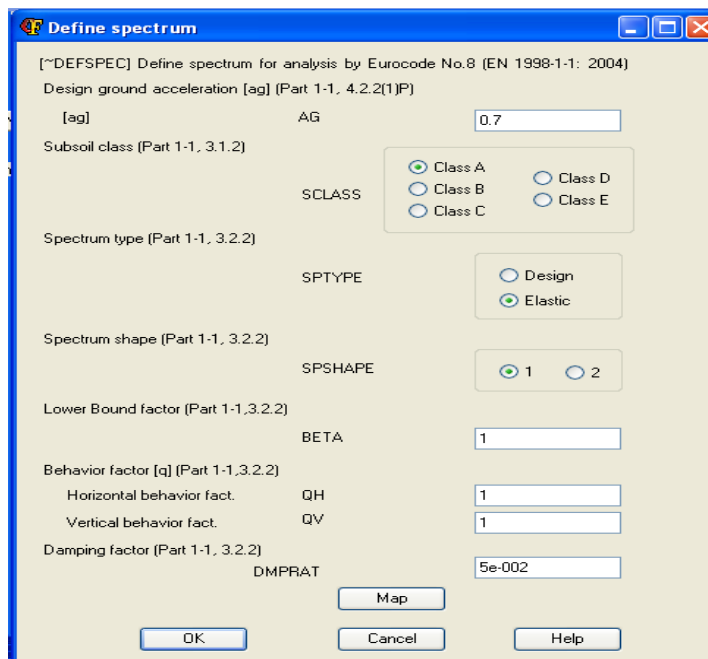
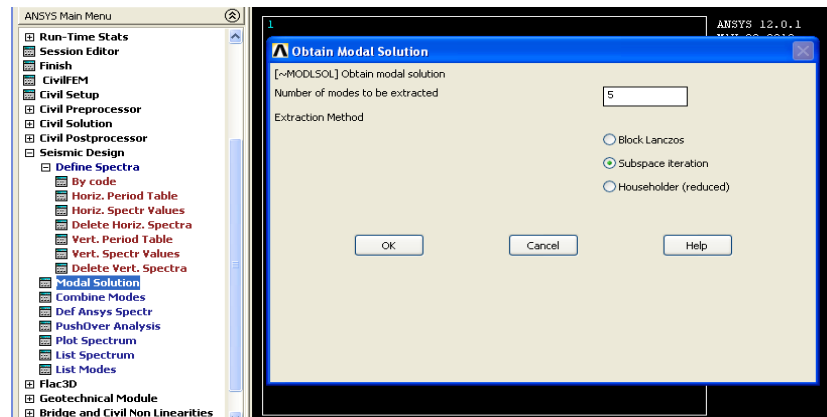


Figure 3-18: Define Spectrum

After define the spectrum, then proceed to the modal solution will be defined. In the modal solution option, selected 5 modes to be extracted and extraction method will be set as subspace iteration, and then click ok to run this analysis. Next, the result will be showed. In this elastic spectrum analysis, we get the plot spectrum in horizontal and vertical component. The period range is about 3.5s.



**Figure 3-19:** Define Modal Solution

## **CHAPTER 4**

### **RESULTS AND DISCUSSION**

#### **4.1 INTRODUCTION**

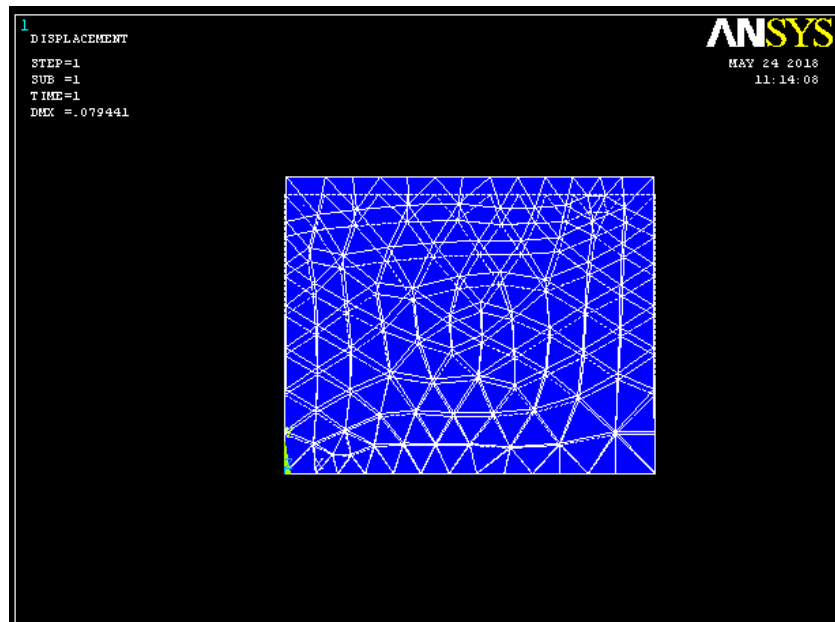
The structural behaviours of unreinforced adobe (non-linear material properties) and also adobe with wire mesh reinforcement (or called reinforced adobe, with bilinear material properties) such as deformation & stress and also seismic analysis will be determined through ANSYS Software. The analysis of adobe models will be based on the data of materials from previous research and some input parameters. These input parameters of adobe materials such as Poisson's Ratio, Density, Young Modulus, were defined in the ANSYS model.

The result will be compared through choosing one of the nodes in the models. For example, node 3 (a point exactly in a corner of the wall) will be selected. After that, we will get the value of the result in that node, then discuss about the difference and outcome based on that value. At the same time, the contour of the deformation and stress will be compare and identify the maximum value. For the seismic analysis, we selected the elastic spectrum analysis, to get the seismic spectrum and the result of mode combination for both models.

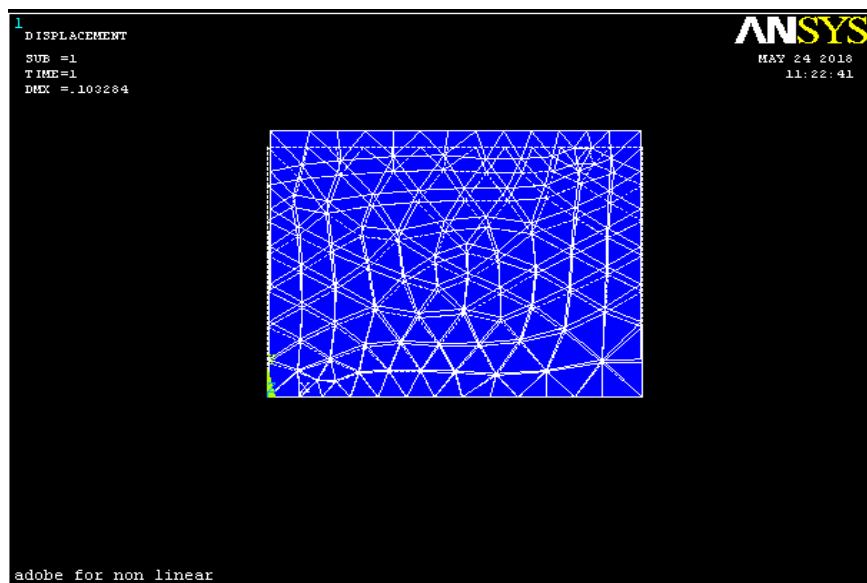
#### **4.2 DEFORMATION OF BOTH MODELS**

The deformation of unreinforced adobe models and adobe models with wire mesh reinforcement will be compared and discussed in this subtopic. To compare the deflection (displacement) of both models after apply the load on the top wall surface area, we get value of displacement of both models in node 3. This subtopic will

compare the x, y and z component of displacement and also the displacement vector sum which is sum of the displacement from three components.

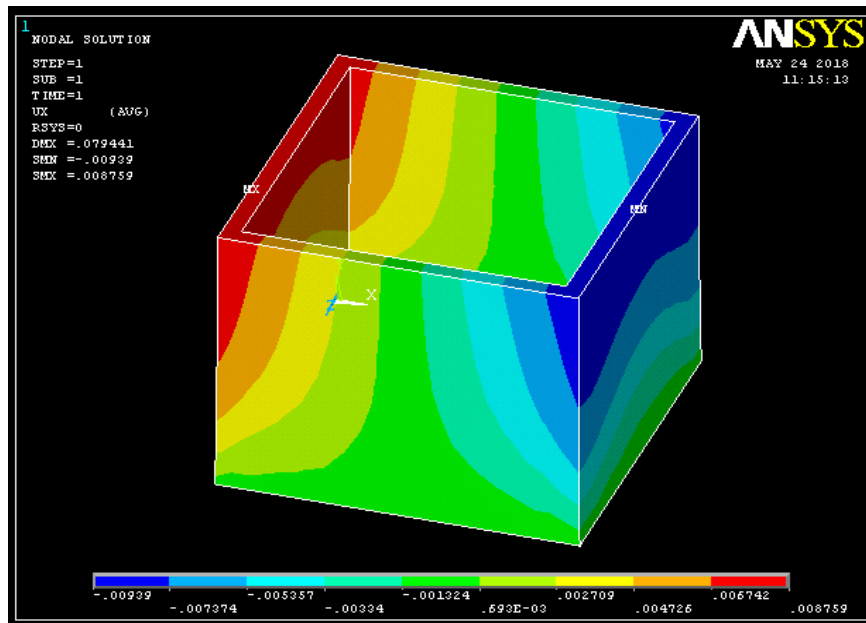


**Figure 4-1:** Deformation shape of reinforced adobe models

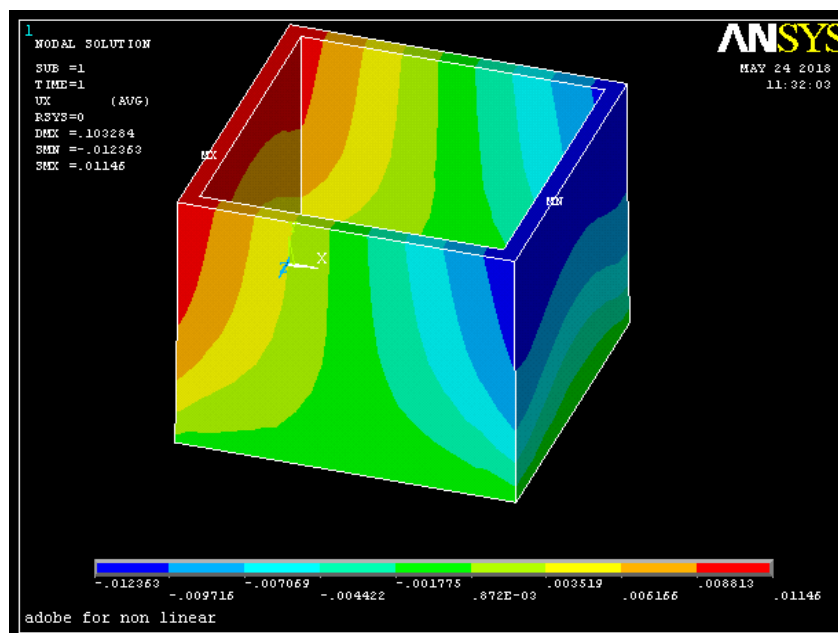


**Figure 4-2:** Deformation shape of unreinforced adobe models

From Figure 4.1 and 4.2, the deformation shape of the unreinforced adobe models show slight more deformation compared to reinforced adobe. It implied that the unreinforced adobe will easily change the shape compared to reinforced adobe.



**Figure 4-3:** X-component displacement of reinforced adobe models

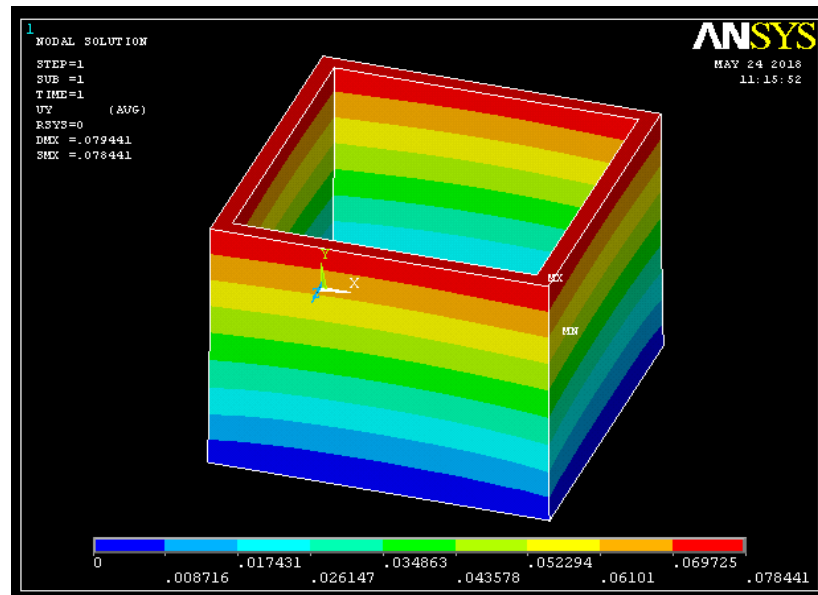


**Figure 4-4** X-component displacement of unreinforced adobe models

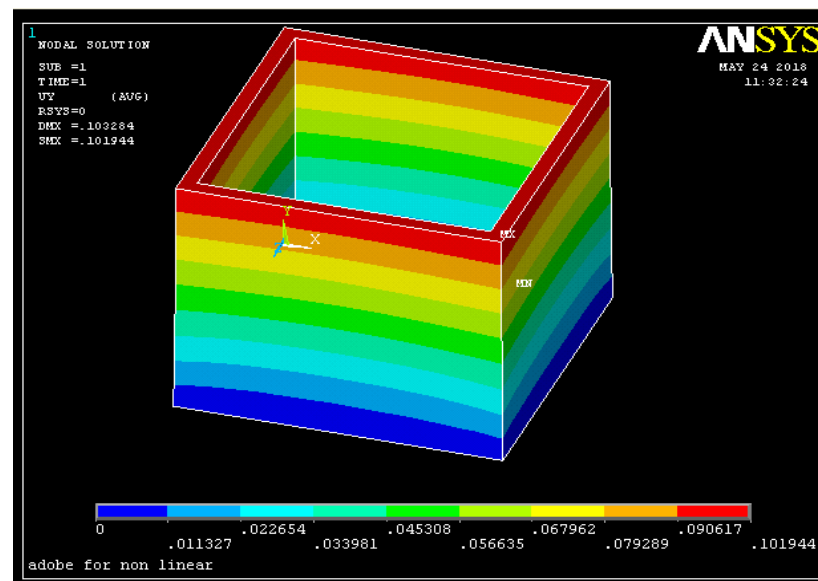
From figure 4.3 and 4.4, we compare the x-component displacement on the node 3. The x-component displacement of reinforced adobe models is  $-0.88119 \times 10^{-02}$  m and for unreinforced adobe models, the x component displacement is about  $-0.11581 \times 10^{-01}$  m. It shows that the displacement is moving in same direction and the magnitude of X-



component displacement of unreinforced adobe models is slightly larger than reinforced adobe models.



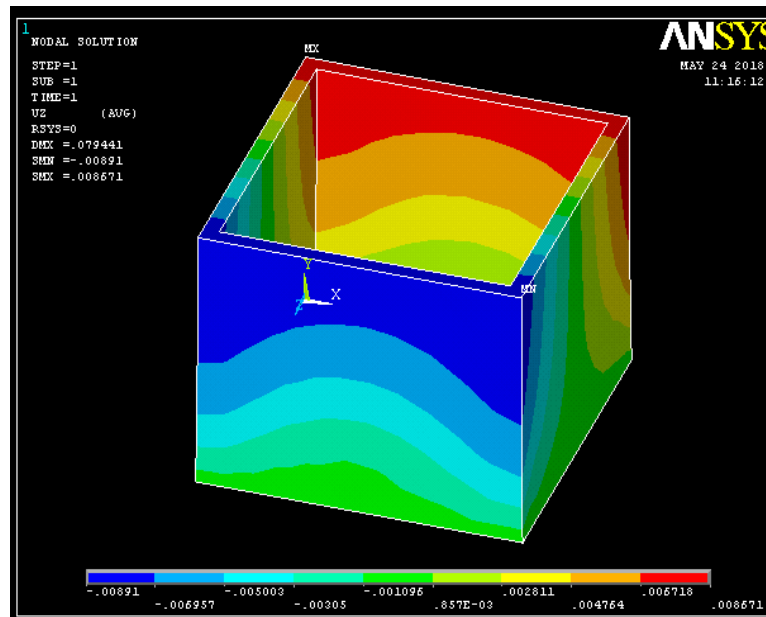
**Figure 4-5:** Y-component displacement of reinforced adobe models



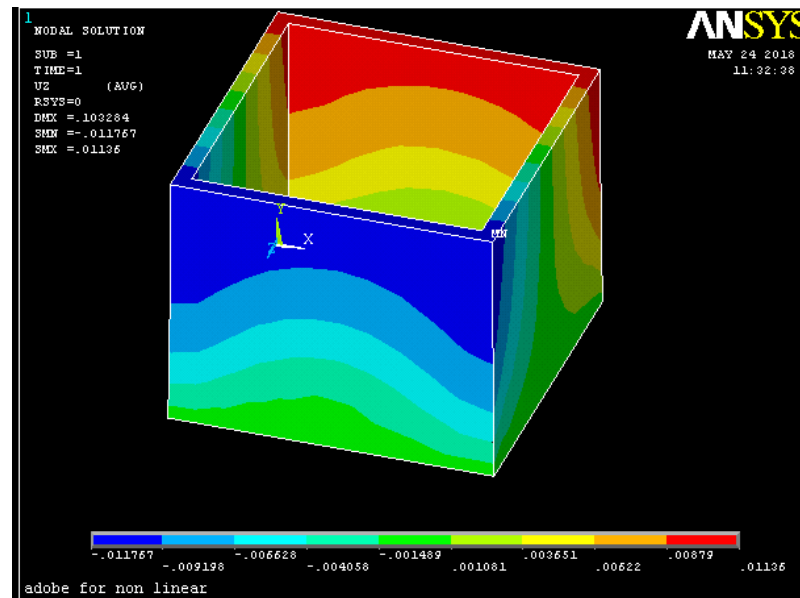
**Figure 4-6:** Y-component displacement of unreinforced adobe models

From figure 4.5 and 4.6, we compare the y-component displacement on the node 3. The y-component displacement of reinforced adobe models is  $0.78305 \times 10^{-01}$  m and for unreinforced adobe models, the y component displacement is 0.10167m. It shows that

the displacement is moving in same direction and the y-component displacement of unreinforced adobe models is larger than reinforced adobe models.



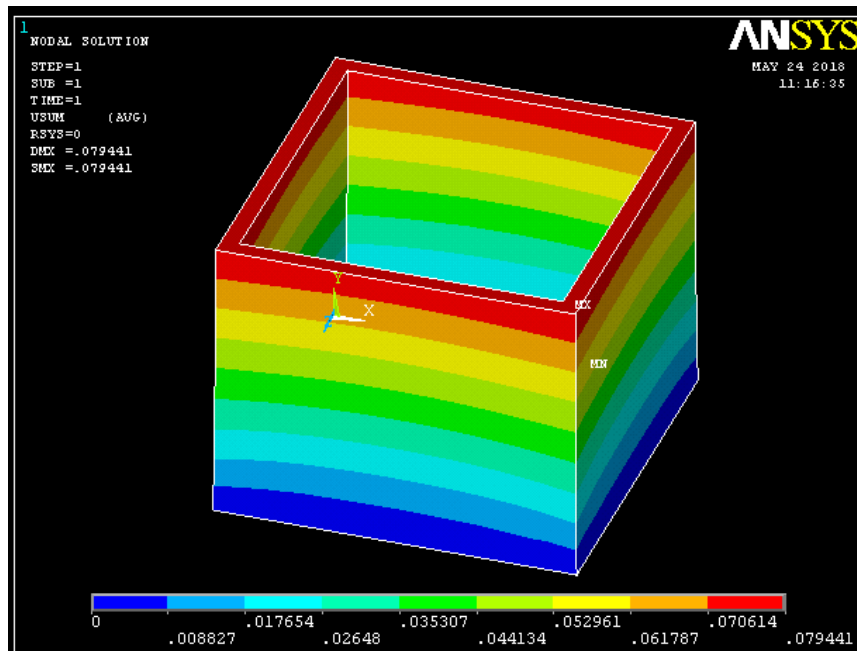
**Figure 4-7:** Z-component displacement of reinforced adobe models



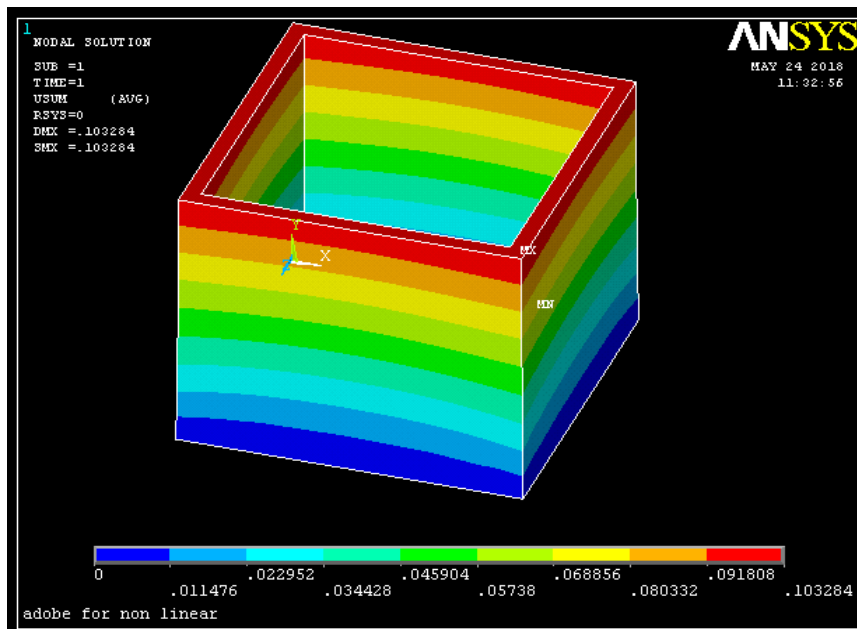
**Figure 4-8:** Z-component displacement of unreinforced adobe models

From figure 4.7 and 4.8, we compare the z-component displacement on the node 3. The z-component displacement of reinforced adobe models is  $0.86470 \times 10^{-02}$  m and for unreinforced adobe models, the z-component displacement is  $0.11279 \times 10^{-01}$  m. It shows

that the displacement is moving in same direction and the z-component displacement of unreinforced adobe models is slightly more than reinforced adobe models.



**Figure 4-9:** Displacement vector sum of reinforced adobe models



**Figure 4-10:** Displacement vector sum of unreinforced adobe models

From figure 4.9 and 4.10, we compare the displacement vector sum on the node 3. The displacement vector sum of reinforced adobe model  $0.79272 \times 10^{-01}$  m and for

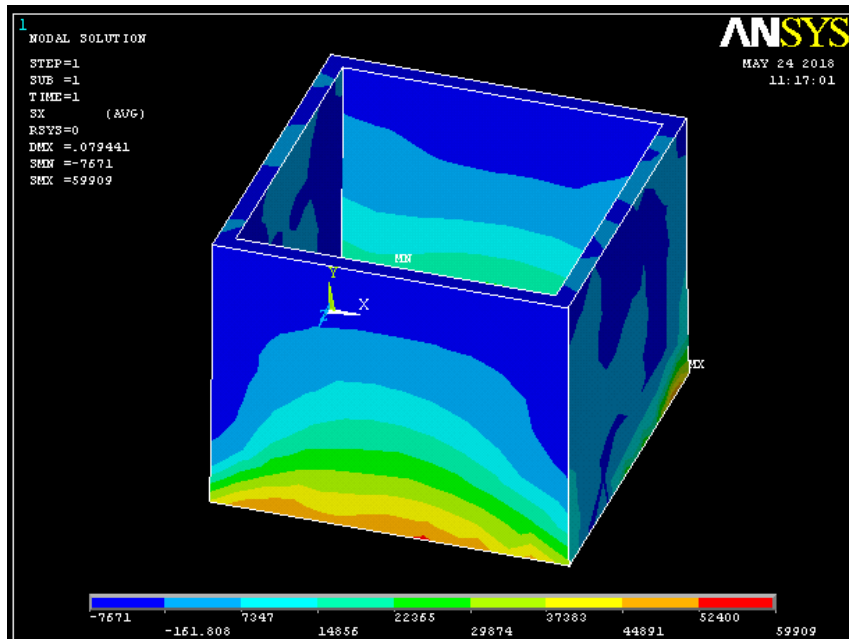
unreinforced adobe model, the displacement vector sum is 0.10295m. It shows the displacement vector sum of unreinforced adobe models is slightly more than reinforced adobe models.

In conclusion, the direction of the displacement for the both models is same (same sign mean same direction), either in positive sign or negative sign. For the magnitude of the displacement, it proves that the unreinforced adobe is larger than reinforced adobe. Unreinforced adobe have deflect more compared to reinforced adobe when carry out static analysis.

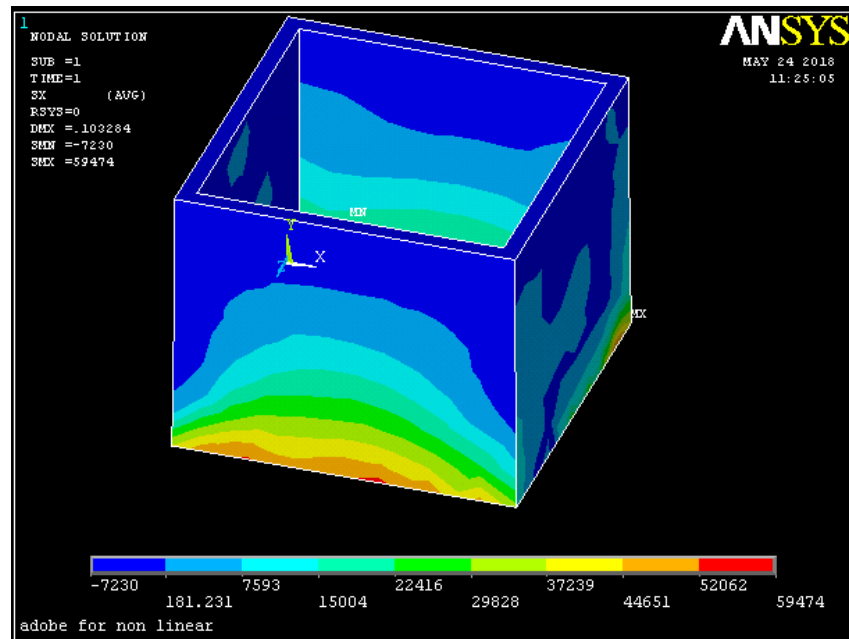
### **4.3 STRESS OF BOTH MODELS**

In this section, the stresses from nodal solutions will be compared. The stresses in nodal solutions consists X, Y, & Z component stress, XY, YZ& XZ shear stress, first to third principal stress, stress intensity, and von Mises stress. Stress intensity is the different between minimum and maximum principal stress whereas von Mises stress can determine whether the models or materials will be fracture or yield. To compare stresses from nodal solutions of both models, the value of stresses in node 3 will be used.

From figure 4.11 and 4.12, we compare the X-component stress on the node 3. The X-component stress of reinforced adobe models is -626.62 Pa. For unreinforced adobe models, the X-component stress is about -612.41 Pa. It shows that the stress is compression stress (negative sign mean compression) and the magnitude of X-component stress of reinforced adobe models is slightly larger than unreinforced adobe models.



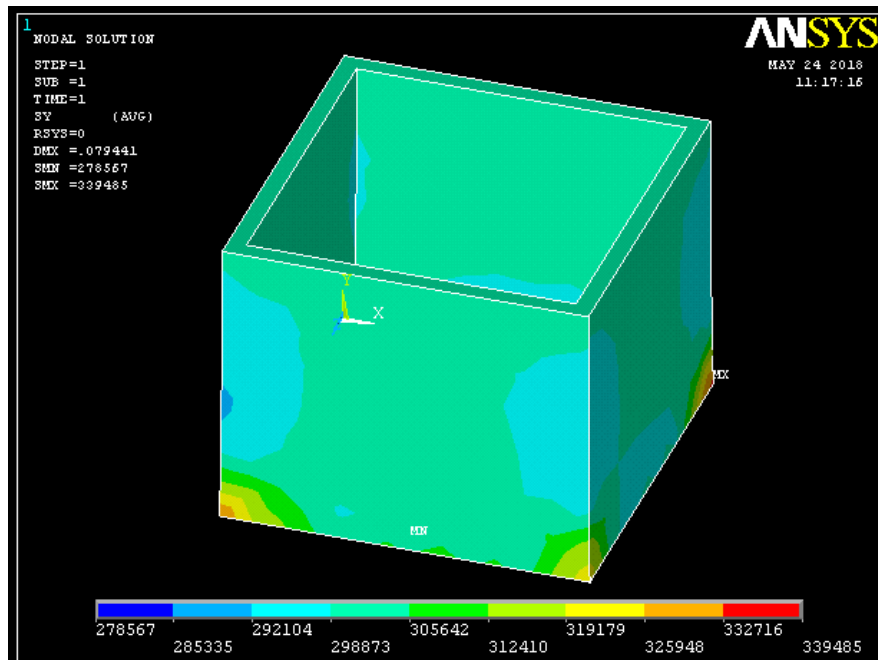
**Figure 4-11:** X- component stress of reinforced adobe models



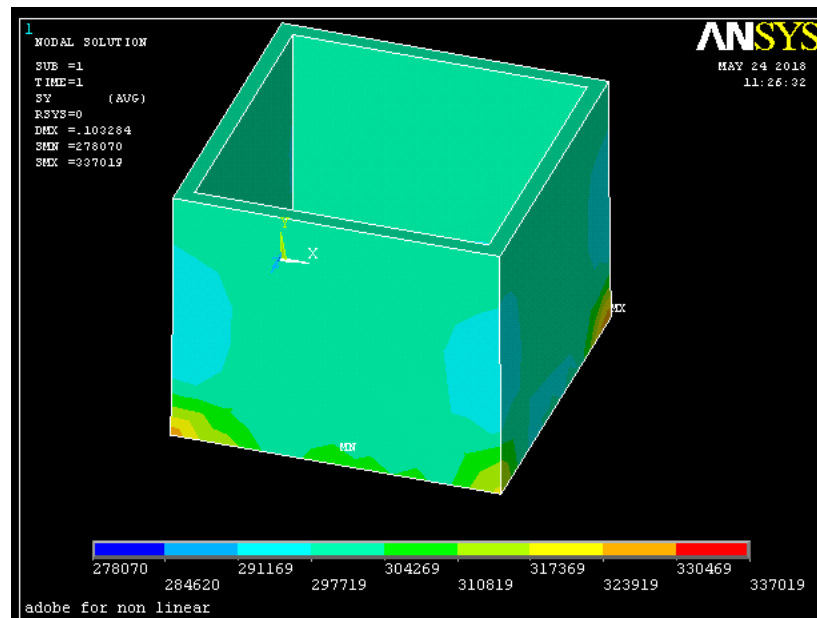
**Figure 4-12:** X-component stress of unreinforced adobe models

From figure 4.13 and 4.14, we compare the Y-component stress on the node 3. The Y-component stress of reinforced adobe models is 0.29959 MPa. For unreinforced adobe models, the Y-component stress is about 0.29948 MPa. It shows that the stress is

tensile stress (positive sign mean tensile stress) and the magnitude of Y-component stress of reinforced adobe models is larger than unreinforced adobe models.



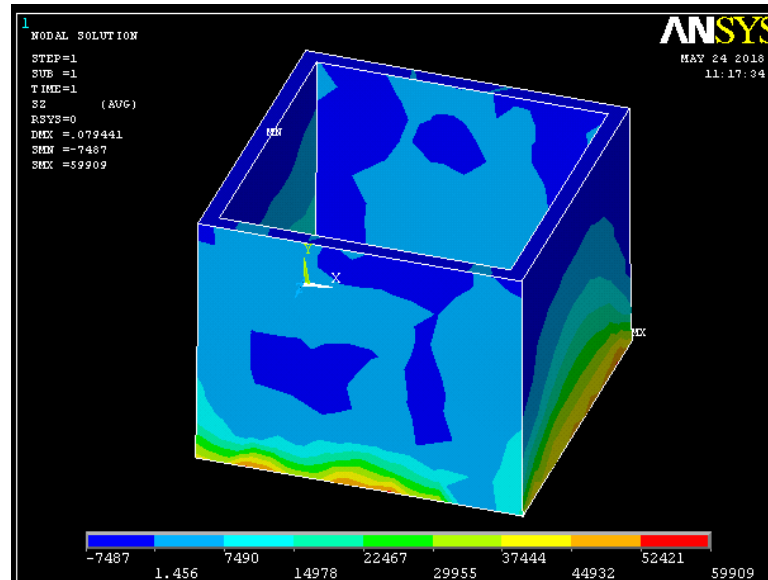
**Figure 4-13:** Y-component stress of reinforced adobe models



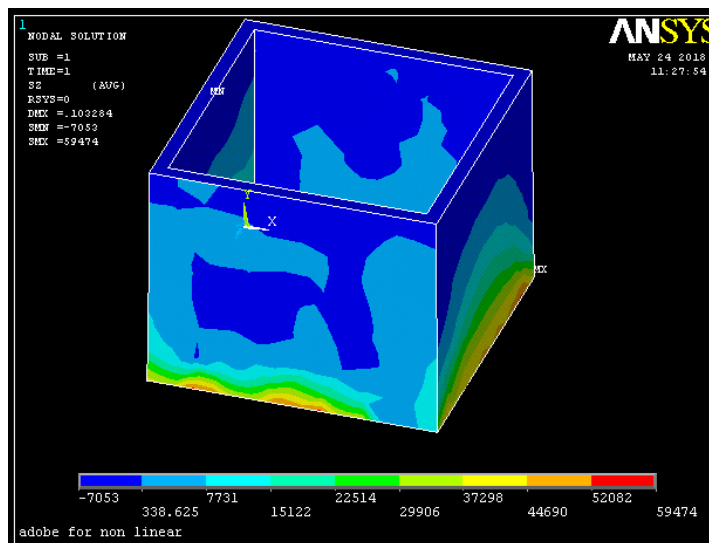
**Figure 4-14:** Y-component stress of unreinforced adobe models

From figure 4.15 and 4.16, we compare the Z-component stress on the node 3. The Z-component stress of reinforced adobe models is -691.23 Pa. For unreinforced adobe

models, the Z-component stress is about -665.36 Pa. It shows that the stress is compression stress (negative sign mean compression) and the magnitude of z-component stress of reinforced adobe models is larger than unreinforced adobe models.



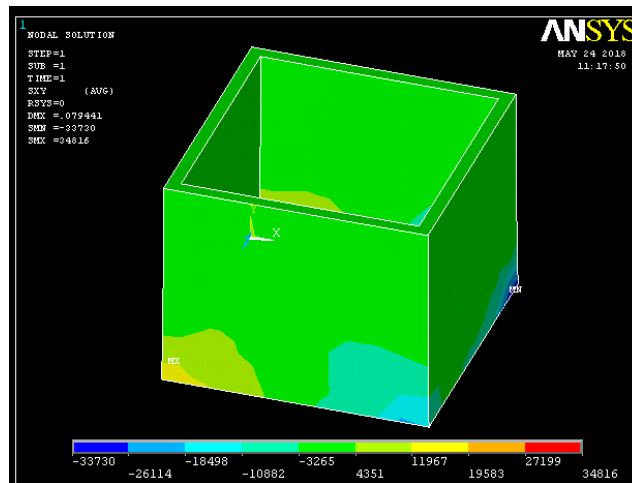
**Figure 4-15:** Z-component stress of reinforced adobe models



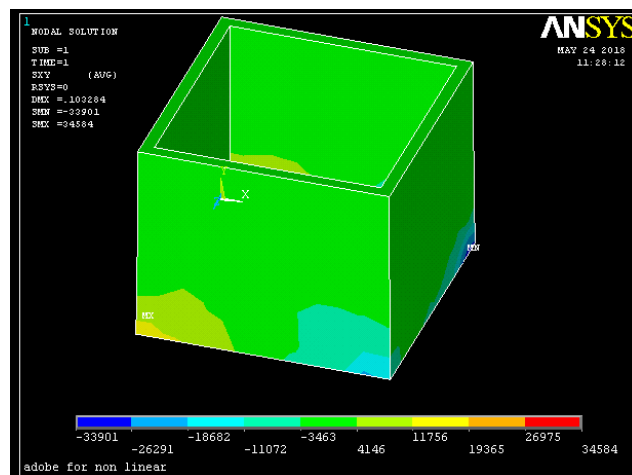
**Figure 4-16:** Z-component stress of unreinforced adobe models

From figure 4.17 and 4.18, we compare the XY shear stress on the node 3. The XY shear stress of reinforced adobe models is 34.562Pa. For unreinforced adobe models, the XY shear stress is about 36.972Pa. It shows that the stress is tensile stress and the

magnitude of XY shear stress of reinforced adobe models is larger than unreinforced adobe models.



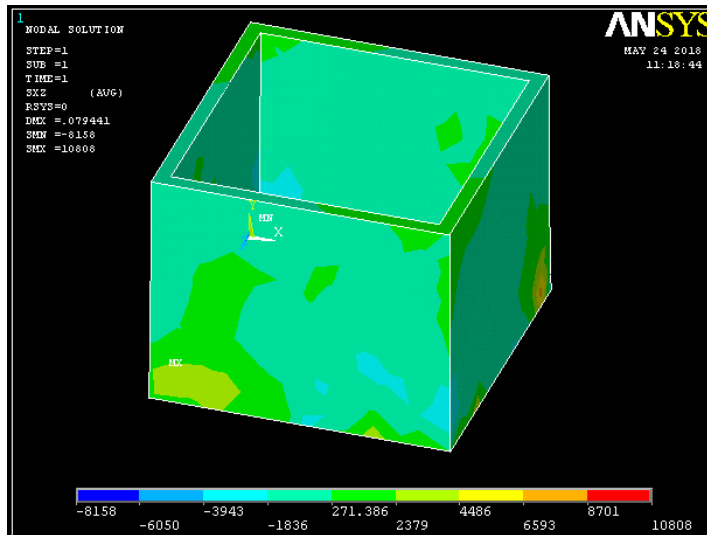
**Figure 4-17:** XY shear stress of reinforced adobe models



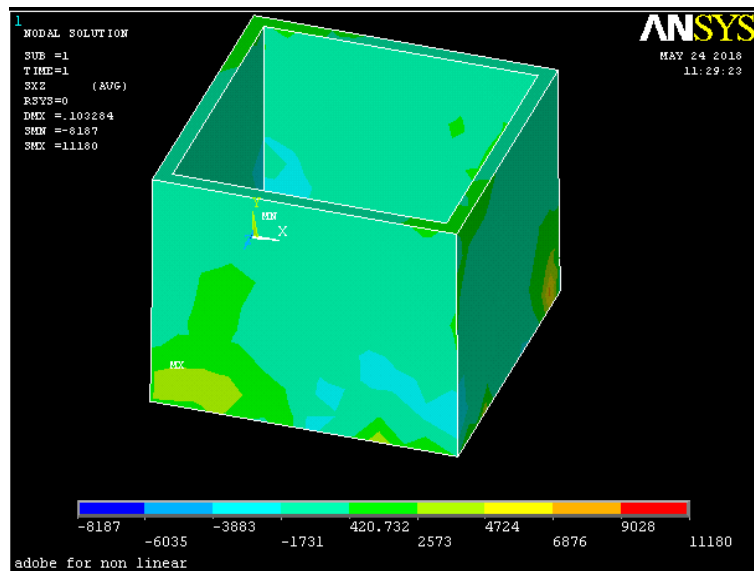
**Figure 4-18:** XY shear stress of unreinforced adobe models

From figure 4.19 and 4.20, we compare the XZ shear stress on the node 3. The XZ shear stress of reinforced adobe models is -474.31Pa. For unreinforced adobe models, the XZ shear stress is about -466.61Pa. It shows that the stress is compression stress (negative sign mean compression) and the magnitude of XZ shear stress of reinforced adobe models is larger than unreinforced adobe models.



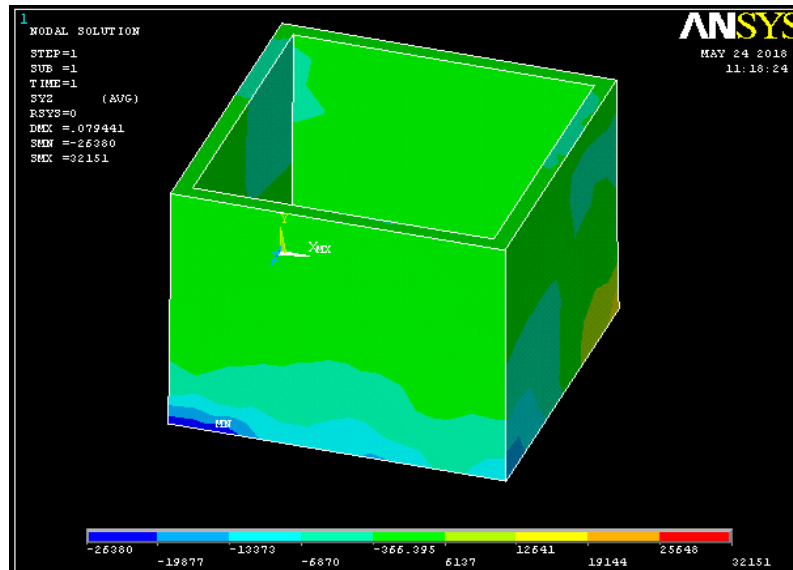


**Figure 4-19: XZ shear stress of reinforced adobe models**

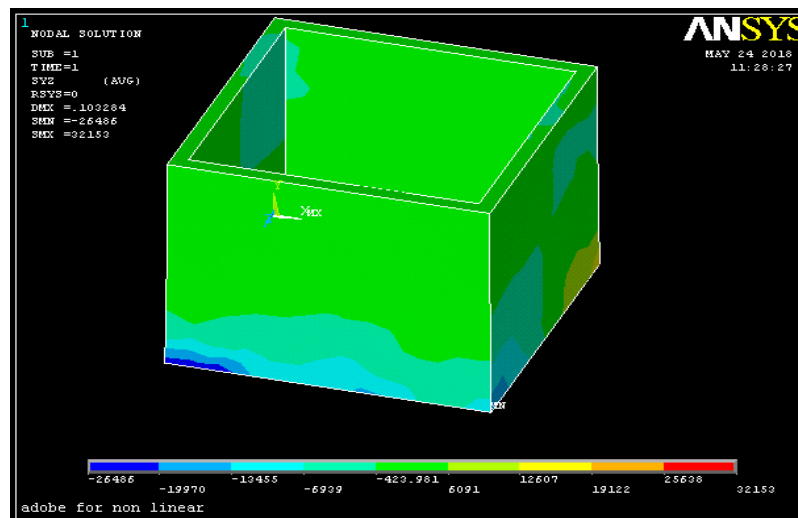


**Figure 4-20: XZ shear stress of unreinforced adobe models**

From figure 4.21 and 4.22, we compare the YZ shear stress on the node 3. The YZ shear stress of reinforced adobe models is -123.97 Pa. For unreinforced adobe models, the YZ shear stress is about -118.45 Pa. It shows that the stress is compression stress (negative sign mean compression) and the magnitude of YZ shear stress of reinforced adobe models is larger than unreinforced adobe models.

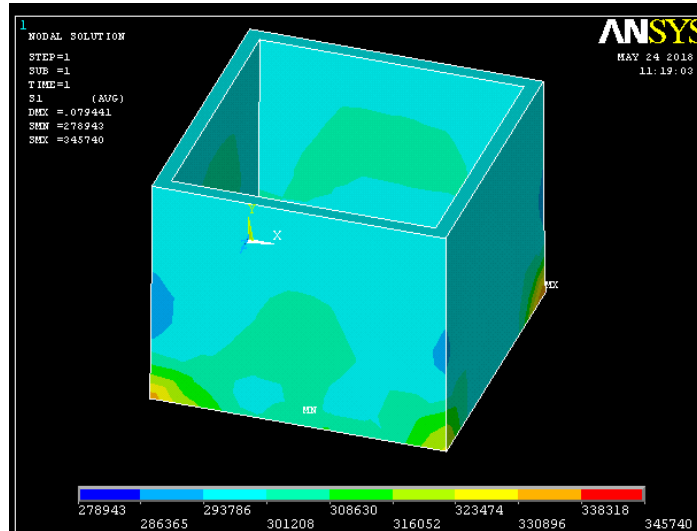


**Figure 4-21:** YZ shear stress of reinforced adobe models

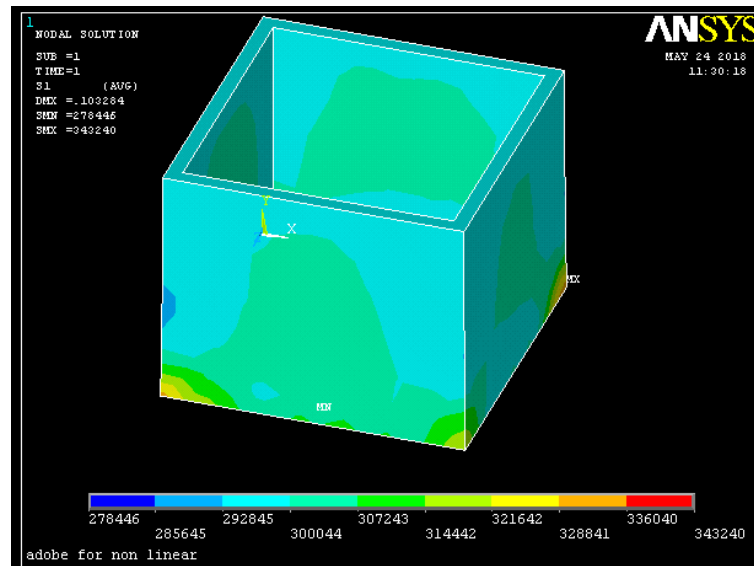


**Figure 4-22:** YZ shear stress of unreinforced adobe models

For next part, we will compare the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> principal stress for both models. The value of these stresses from node 3 will be compared. From figure 4.23 and 4.24, we compare the 1<sup>st</sup> principal stress on the node 3. The 1<sup>st</sup> principal stress of reinforced adobe models is 0.29959 MPa, the 1st principal stress for unreinforced adobe models is 0.29948 MPa.

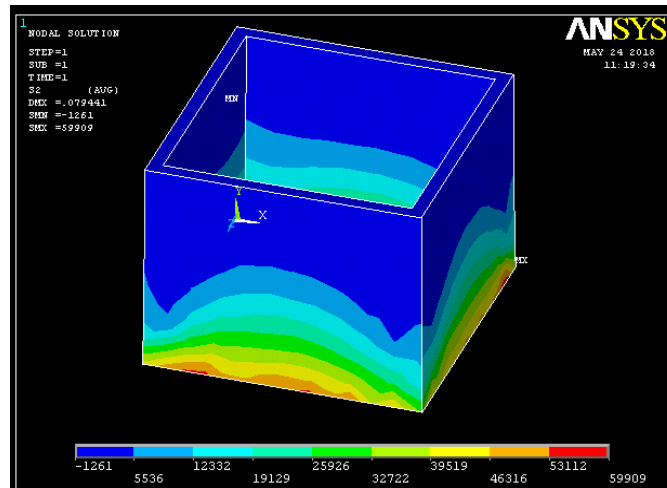


**Figure 4-23:** 1st principal stress of reinforced adobe models

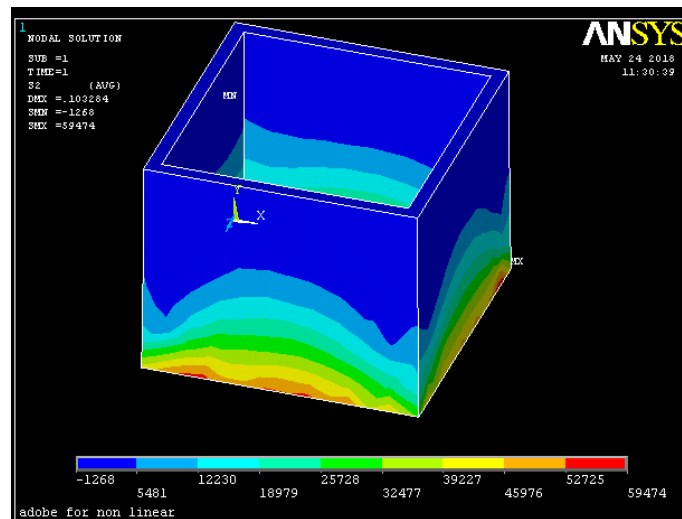


**Figure 4-24:** 1st principal stress of unreinforced adobe models

From figure 4.25 and 4.26, we compare the 2<sup>nd</sup> principal stress on the node 3. The 1<sup>st</sup> principal stress of reinforced adobe models is -179.35Pa, the 2<sup>nd</sup> principal stress for unreinforced adobe models is -168.56 Pa.

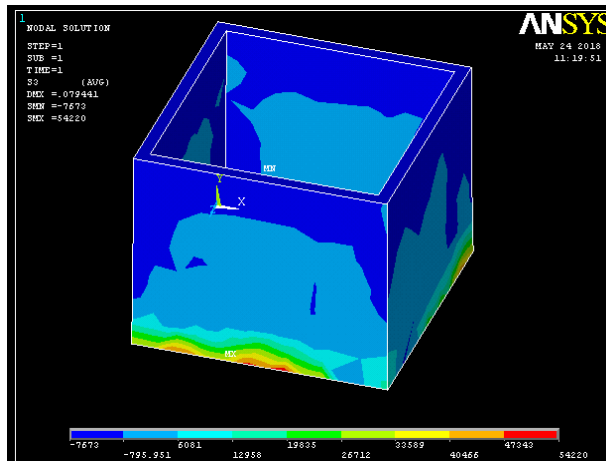


**Figure 4-25:** 2nd principal stress of reinforced adobe models

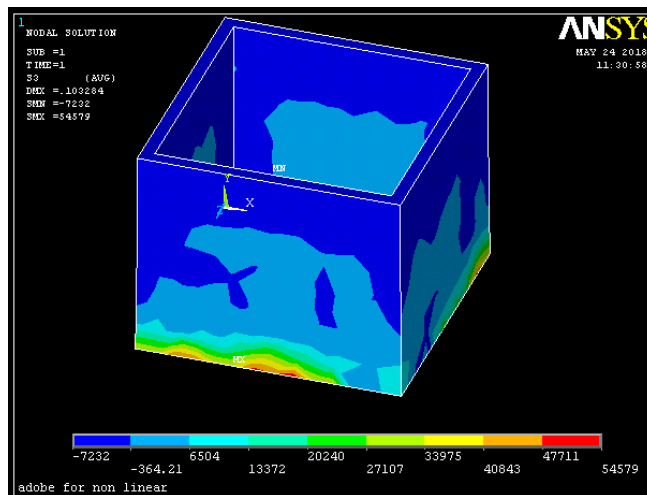


**Figure 4-26:** 2nd principal stress of unreinforced adobe models

From figure 4.27 and 4.28, we compare the 3<sup>rd</sup> principal stress on the node 3. The 1<sup>st</sup> principal stress of reinforced adobe models is -1138.6 Pa, the 3<sup>rd</sup> principal stress for unreinforced adobe models is -1109.3Pa.

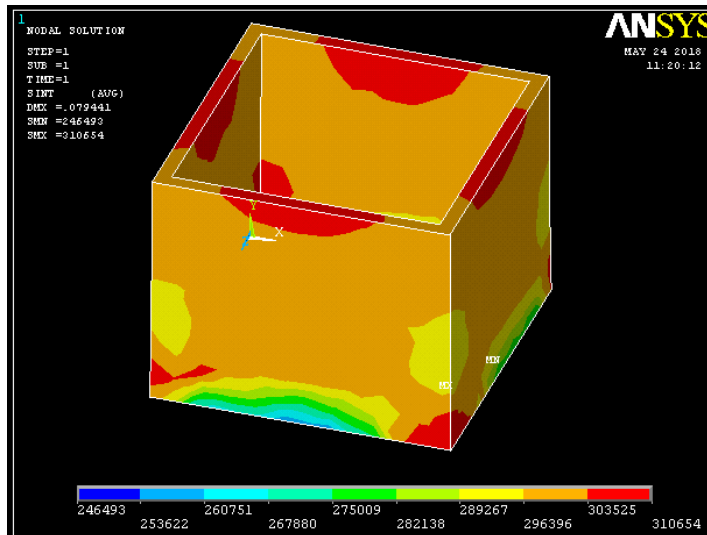


**Figure 4-27:** 3rd principal stress of reinforced adobe models

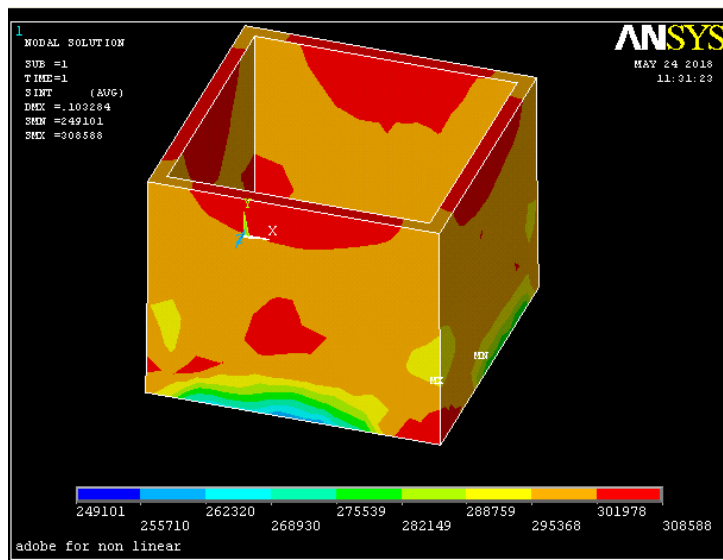


**Figure 4-28:** 3rd principal stress of unreinforced adobe models

Next, the contour of the stress intensity and value of the stress intensity on node 3 will be compared. The value of stress intensity of reinforced adobe is 0.30073 MPa and for unreinforced adobe is 0.30059 MPa. Therefore, we can know that the stress intensity for reinforced adobe is larger than unreinforced adobe.

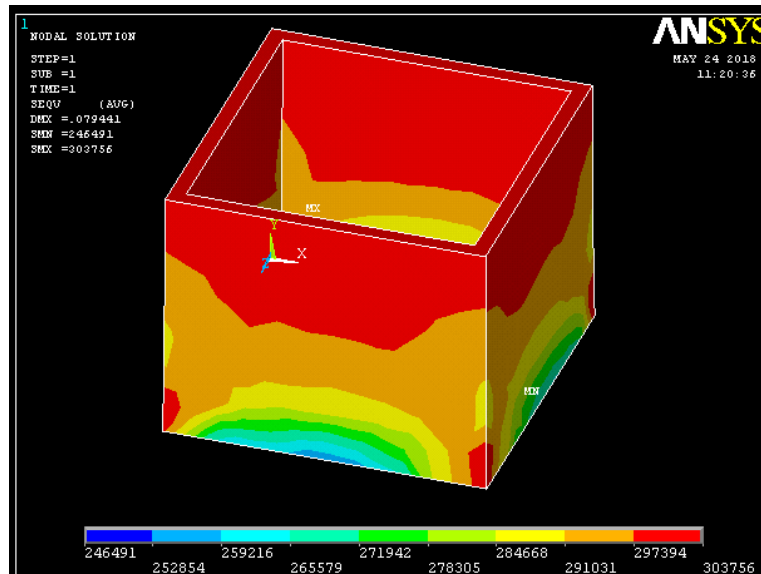


**Figure 4-29:** Stress intensity of reinforced adobe models

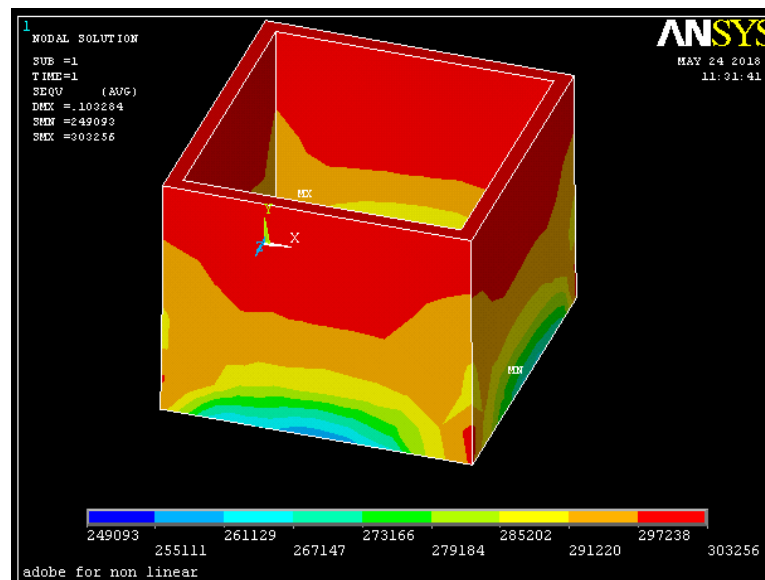


**Figure 4-30:** Stress intensity of unreinforced adobe models

Last but not least, the contour of the von Mises stress and value of the von Mises stress on node 3 will be compared. The value of von Mises stress of reinforced adobe is about 0.30025 MPa and for unreinforced adobe is 0.30012MPa. Therefore, we can know that the von Mises stress for reinforced adobe is larger than unreinforced adobe.



**Figure 4-31:** Von Mises stress of reinforced adobe models

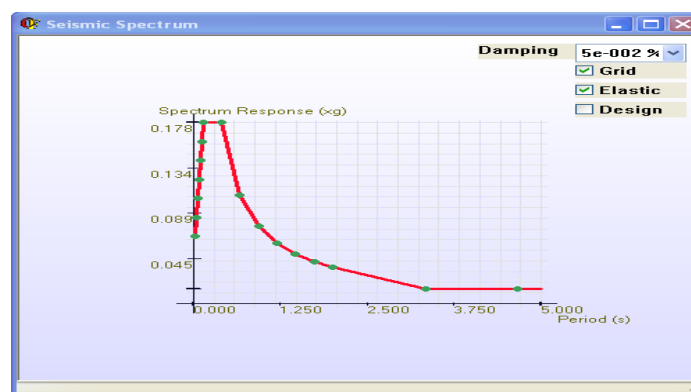


**Figure 4-32:** Von Mises stress of unreinforced adobe models

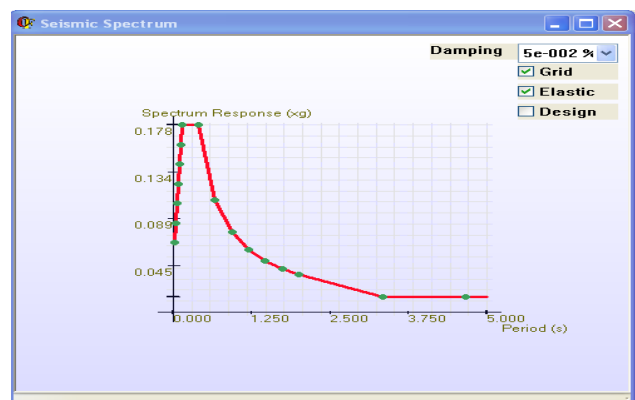
In conclusion, most of stresses of the reinforced adobe model (bilinear material properties) are larger than the unreinforced adobe model (non-linear properties) whereas the XY shear stress of the unreinforced adobe model is larger than reinforced adobe model.

#### 4.4 SEISMIC ANALYSIS OF BOTH MODELS

From the seismic analysis, we can get the 5 mode of different models. In this analysis, there have some few analysis will be conducted. Firstly, the modal analysis of both models will be conducted with 5 modes shapes. Figure 4.35 and figure 4.36 shows the spectrum horizontal component of reinforced adobe models and unreinforced adobe models. The table 4.1 and 4.2 shows the value of elastic spectrum of reinforced adobe model unreinforced adobe model. From t table 4.3 and 4.4, it shows the 5 mode combination results of reinforced adobe model unreinforced adobe model in X, Y and Z directions. The table show the different value of period, frequency and also angular frequency ( $\omega$ ) for both models.



**Figure 4-33:** Spectrum horizontal component of reinforced adobe models



**Figure 4-34:** Spectrum horizontal component unreinforced adobe models



*Spectrum type: Elastic (selected for the analysis) - Damping 5.000000000000000E-002%*

Period (s)	Frequency (1/s)	Horizontal Spectrum (Normalized by gravity)	Vertical Spectrum (Normalized by gravity)
0.000E+00	Infinity	97.023E-03	93.776E-03
50.000E-03	20.000E+00	131.247E-03	271.111E-03
100.000E-03	10.000E+00	191.138E-03	271.111E-03
150.000E-03	6.667E+00	251.029E-03	271.111E-03
200.000E-03	5.000E+00	251.029E-03	224.635E-03
250.000E-03	4.000E+00	251.029E-03	178.159E-03
300.000E-03	3.333E+00	251.029E-03	136.747E-03
350.000E-03	2.857E+00	251.029E-03	120.659E-03
400.000E-03	2.500E+00	251.029E-03	104.571E-03
450.000E-03	2.222E+00	232.202E-03	91.126E-03
500.000E-03	2.000E+00	213.374E-03	82.965E-03

**Table 4-1:** Elastic spectrum of reinforced adobe models

*Spectrum type: Elastic (selected for the analysis) - Damping 5.000000000000000E-002%*

Period (s)	Frequency (1/s)	Horizontal Spectrum (Normalized by gravity)	Vertical Spectrum (Normalized by gravity)
0.000E+00	Infinity	97.023E-03	93.776E-03
50.000E-03	20.000E+00	131.247E-03	271.111E-03
100.000E-03	10.000E+00	191.138E-03	271.111E-03
150.000E-03	6.667E+00	251.029E-03	271.111E-03
200.000E-03	5.000E+00	251.029E-03	224.635E-03
250.000E-03	4.000E+00	251.029E-03	178.159E-03
300.000E-03	3.333E+00	251.029E-03	136.747E-03
350.000E-03	2.857E+00	251.029E-03	120.659E-03
400.000E-03	2.500E+00	251.029E-03	104.571E-03
450.000E-03	2.222E+00	232.202E-03	91.126E-03
500.000E-03	2.000E+00	213.374E-03	82.965E-03

**Table 4-2:** Elastic spectrum of unreinforced adobe models

**LIST OF MODES (MODE COMBINATION RESULTS)**

**From 1 to 5**

*X Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	431.810E-03	2.318E+00	14.551E+00	-	10.985E+00	120.238E+00
2	388.280E-03	2.589E+00	16.288E+00	-	-808.570E-03	387.922E-03
3	385.780E-03	2.592E+00	16.288E+00	-	80.808E+00	6.530E+03
4	283.290E-03	3.530E+00	22.180E+00	-	5.108E+00	26.089E+00
5	280.940E-03	3.559E+00	22.385E+00	-	1.195E+00	1.428E+00

*Y Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	431.810E-03	2.318E+00	14.551E+00	-	25.782E-03	664.888E-08
2	388.280E-03	2.589E+00	16.288E+00	-	-25.249E-03	637.517E-08
3	385.780E-03	2.592E+00	16.288E+00	-	-24.840E-03	607.125E-08
4	283.290E-03	3.530E+00	22.180E+00	-	-1.041E+00	1.083E+00
5	280.940E-03	3.559E+00	22.385E+00	-	-180.040E-03	32.414E-03

*Z Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	431.810E-03	2.318E+00	14.551E+00	-	3.055E+00	9.330E+00
2	388.280E-03	2.589E+00	16.288E+00	-	81.424E+00	6.830E+03
3	385.780E-03	2.592E+00	16.288E+00	-	84.348E-03	7.115E-03
4	283.290E-03	3.530E+00	22.180E+00	-	-1.213E+00	1.471E+00
5	280.940E-03	3.559E+00	22.385E+00	-	1.059E+00	1.122E+00

**Table 4-3: Mode Response of reinforced adobe models**

**LIST OF MODES (MODE COMBINATION RESULTS)**

**From 1 to 5**

*X Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	443.440E-03	2.255E+00	14.189E+00	-	10.985E+00	120.239E+00
2	396.890E-03	2.521E+00	15.839E+00	-	-808.570E-03	387.921E-03
3	396.150E-03	2.524E+00	15.881E+00	-	80.808E+00	6.530E+03
4	290.920E-03	3.437E+00	21.598E+00	-	5.108E+00	26.070E+00
5	288.510E-03	3.466E+00	21.778E+00	-	1.195E+00	1.428E+00

*Y Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	443.440E-03	2.255E+00	14.189E+00	-	25.805E-03	665.914E-08
2	396.890E-03	2.521E+00	15.839E+00	-	-25.249E-03	637.520E-08
3	396.150E-03	2.524E+00	15.881E+00	-	-24.840E-03	607.118E-08
4	290.920E-03	3.437E+00	21.598E+00	-	-1.041E+00	1.083E+00
5	288.510E-03	3.466E+00	21.778E+00	-	-180.030E-03	32.412E-03

*Z Direction*

Mode	Period (s)	Frequency (1/s)	Omega (1/s)	Combination Coefficient	Participation Factor	Effective Mass
1	443.440E-03	2.255E+00	14.189E+00	-	3.055E+00	9.330E+00
2	396.890E-03	2.521E+00	15.839E+00	-	81.424E+00	6.830E+03
3	396.150E-03	2.524E+00	15.881E+00	-	84.348E-03	7.115E-03
4	290.920E-03	3.437E+00	21.598E+00	-	-1.213E+00	1.471E+00
5	288.510E-03	3.466E+00	21.778E+00	-	1.059E+00	1.122E+00

**Table 4-4 Mode Response of unreinforced adobe models**

To compare the modes combination of reinforced adobe (bilinear material model) and unreinforced adobe (nonlinear material model), the average of the parameters will be calculated. These parameters consists three directions.

Models	Direction	Average period (s)	Average frequency (1/s)	Average angular frequency (1/s)
Reinforced adobe model	X	0.349	2.917	18.33
	Y	0.349	2.917	18.33
	Z	0.349	2.917	18.33
Unreinforced adobe model	X	0.361	2.8406	17.869
	Y	0.361	2.8406	17.869
	Z	0.631	2.8406	17.869

**Table 4-5:** Average period, frequencies of both models

From Table 4.5, the average period of reinforced adobe model is smaller than unreinforced adobe model. The period is inversely proportional to frequency, mean that the smaller the period, the higher the frequency. Therefore, reinforced adobe model have higher frequency compare to unreinforced adobe model. Higher frequency will have low amplitude, which will have less damage to the building. This implied that the reinforced adobe model will have less damage when under seismic load compared to unreinforced adobe model.

## **CHAPTER 5**

### **CONCLUSION AND RECOMMENDATION**

#### **5.1 INTRODUCTION**

In this chapter, the objectives and outcomes of this study will be concluded. Based on the conclusion, some recommendations were included to structure behaviours for both adobe models.

#### **5.2 CONCLUSION**

The objectives of the study were to model the adobe structure behaviour using bilinear material model and to study the behaviour of adobe structure subjected to seismic load. The wire mesh reinforced adobe (bilinear material properties) model and unreinforced adobe model (non-linear material properties) will undergoes static analysis and subjected to load in seismic analysis. The following conclusion can be made based on the outcomes.

- 1) Adobe structures model with wire mesh reinforcement have smaller deflection compared to unreinforced adobe. The wire mesh reinforcement provided sufficient strength to support the structure, therefore the structure not easy to deflect during static analysis.

- 2) For the adobe structures model with wire mesh reinforcement, it have higher the nodal stresses like principal stress, component stress, von Mises stress and stress intensity compared to unreinforced adobe structure model.
- 3) During the seismic analysis, it shows that the average frequency of reinforced adobe models is higher that unreinforced adobe model whereas reinforced adobe models have shorter period than unreinforced adobe model.
- 4) The mode combination of reinforced adobe model shows the higher frequency and low amplitude during undergoes seismic load, which mean reinforced adobe model have less damage when earthquake.

### **5.3 RECOMMENDATION**

The recommendations for this study are mentions below:

- 1) The adobe structures should added with the wire mesh reinforcement in order to minimize the damage of the building when undergo seismic load.
- 2) The meshing accuracy should use the suitable test load in order get the result without error and to ensure the mesh size is accuracy. The smaller the mesh size will get more accurate result.
- 3) The design load from roof should be considered and with suitable load number to get the different in structure behaviour, too small load will not see the difference of structure behaviour.

## REFERENCES

Arthur, B. (2015). In Yemen, there's a city full of 500 year old skyscrapers made of mud. (Article) <http://www.citymetric.com/skylines/yemen-theres-city-full-500-year-old-skyscrapers-made-mud-1462> [Accessed 28 Nov. 2017].

Bijl, A. (2015). In Yemen, there's a city full of 500 year old skyscrapers made of mud | CityMetric. [online] Citymetric.com. Available at: <http://www.citymetric.com/skylines/yemen-theres-city-full-500-year-old-skyscrapers-made-mud-1462> [Accessed 28 Nov. 2017].

Brown, P., & Clifton, J. (1978). Adobe. I: The Properties of Adobe. *Studies in Conservation*, 23(4), 139-146. Available at: <https://www.jstor.org/stable/1505842>. [Accessed 28 Nov. 2017].

CHAMBERS, J. and KELLY, T. (2004). NONLINEAR DYNAMIC ANALYSIS – THE ONLY OPTION FOR IRREGULAR STRUCTURES. In: 13th World Conference on Earthquake Engineering Vancouver, B.C.. [online] Canada, .Paper No. 1389. Available at: [http://www.iitk.ac.in/nicee/wcee/article/13\\_1389.pdf](http://www.iitk.ac.in/nicee/wcee/article/13_1389.pdf) [Accessed 30 Nov. 2017].

Dainese, E. (2015). Great Mosque of Djenné. [online] Available at: <https://www.khanacademy.org/humanities/art-africa/west-africa/mali1/a/great-mosque-of-djennen> [Accessed 20 Nov. 2017].

Dowling, D.M.. (2004). Adobe housing in El Salvador: Earthquake performance and seismic improvement. 375. Page 281-300. 10.1130/0-8137-2375-2.281.

Edward W. Smith (1982). Adobe bricks in New Mexico. Circular 188. *Publish by New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico USA*

Fea-cae-engineering.com. (2006 - 2014). Element Types. [online] Available at: [http://fea-cae-engineering.com/FEA-CAE-Engineering/element\\_types.htm](http://fea-cae-engineering.com/FEA-CAE-Engineering/element_types.htm) [Accessed 28 Nov. 2017].

Femto Engineering. (2017). In short explained: Linear and nonlinear structural analysis. [online] Available at: <https://www.femto.eu/stories/linear-non-linear-analysis-explained> [Accessed 29 Nov. 2017].

Güney, D. and Aydın, E. (2015). The evaluation of damage mechanism of unreinforced masonry buildings after Van (2011) and Elazig (2010) Earthquakes. In: Journal of Physics: Conference Series. [online] Available at: <http://iopscience.iop.org/article/10.1088/1742-6596/628/1/012066/pdf> [Accessed 27 Nov. 2017].

Illampas, R., Charmpis, D. and Ioannou, I. (2014). Laboratory testing and finite element simulation of the structural response of an adobe masonry building under horizontal loading. *Engineering Structures*, 80, pp.362-376.

Islam, M. and Watanabe, H. (2004). FEM SIMULATION OF SEISMIC BEHAVIOUR OF ADOBE STRUCTURES. In: *13th World Conference on Earthquake Engineering Vancouver, B.C.*, [online] Canada, p.1310. Available at: [http://www.iitk.ac.in/nicee/wcee/article/13\\_1310.pdf](http://www.iitk.ac.in/nicee/wcee/article/13_1310.pdf) [Accessed 7 Dec. 2017].

ITTI Update (2008). Introduction to Finite Element Analysis. Publication University of Manchester 2010

MacLeod, F. (2015). The 'Manhattan of the Desert': Shibam, Yemen's Ancient Skyscraper City. [online] ArchDaily. Available at: <https://www.archdaily.com/771154/the-manhattan-of-the-desert-shibam-yemens-ancient-skyscraper-city> [Accessed 28 Nov. 2017].

Mamaghani, Mo & Ataei, Hossein & Bhatia, Shobha & Lui, Eric. (2016). Nonlinear Finite Element Analysis of Adobe Structures Strengthened by Synthetic Nylons. XXIV ICTAM, 21-26 August 2016, Canada Available at: [https://www.researchgate.net/publication/307451344\\_Nonlinear\\_Finite\\_Element\\_Analysis\\_of\\_Adobe\\_Structures\\_Strengthened\\_by\\_Synthetic\\_Nylons](https://www.researchgate.net/publication/307451344_Nonlinear_Finite_Element_Analysis_of_Adobe_Structures_Strengthened_by_Synthetic_Nylons) [Accessed 2 Dec 2017].

Neville Agnew, H. (1990). 6th International Conference on Earthen Architecture. Hdl.handle.net. Available at: [http://hdl.handle.net/10020/gci\\_pubs/adobe90](http://hdl.handle.net/10020/gci_pubs/adobe90) [Accessed 18 Nov. 2017].

Olukoya Obafemi, A. and Kurt, S. (2016). Environmental impacts of adobe as a building material: The north cyprus traditional building case. *Case Studies in Construction Materials*, [online] 4, pp.32-41. Available at: <https://www.sciencedirect.com/science/article/pii/S2214509515300176> [Accessed 1 May 2018].

Rodriguez, C. (n.d.). Ingeciber S.A. - Software Partner | ANSYS. Available at :<http://www.ansys.com/about-ansys/partner-ecosystem/software-partners/ingeciber> [Accessed 2 Dec 2017].

Sir Robert McAlpine (n.d.). Supporting Sir Robert McAlpine with ANSYS and CivilFEM. Available at : <http://wildeanalysis.co.uk/resource/case-study-ansys-civilfem-software-sir-robert-mcalpine-support> [Accessed 2 Dec 2017].

S. S. Bhavikatti, (2005). Finite Element Analysis. Publish by New Age International.

TheGreenJump. (2017). Adobe Brick. [Website] [Accessed 10 Nov. 2017]. Available at: <http://www.thegreenjump.com/adobe-brick.html>

Wai, C M. (2013). Modelling optimization involving different types of elements in finite element analysis IOP Conference Series: Materials Science and Engineering 50 012036. <http://iopscience.iop.org/article/10.1088/1757-899X/50/1/012036/pdf> [Accessed 10 Nov. 2017].

Yannu, F. (2009). Static Vs Dynamic Finite Element Analysis. [http://fajaryannu.blogspot.my/2009/06/static-vs-dynamic-finite-element\\_21.htm](http://fajaryannu.blogspot.my/2009/06/static-vs-dynamic-finite-element_21.htm) [Accessed 29 Nov 2017].