UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS♦

JUDUL: **MODELING ANALYSIS OF MENISCUS OF KNEE JOINT DURING SOCCER KICKING**

SESI PENGAJIAN: 2012/2013

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MODELING ANALYSIS OF MENISCUS OF KNEE JOINT DURING SOCCER KICKING

MOHD FIRDAUS BIN MOHD JAAFAR

Report submitted in partial fulfillment of the requirements
for the award of the degree of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
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JUNE 2013

EXAMINER'S DECLARATION

I certify that the project entitled "*Modeling Analysis of Meniscus of Knee Joint During Soccer Kicking*" is written by *Mohd Firdaus bin Mohd Jaafar*. I have examined the final copy of this project and in my opinion, it is fully adequate in terms of language standard and report formatting requirement for the award of the degree of Bachelor Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor Mechanical Engineering.

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Specially dedicated to

My beloved family, friends for their support,

encouragement and always be there during my hard times.

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ABSTRACT

The meniscus is important in many aspects of knee function. The placement of meniscus where been located between the two bones of femur and tibia gives an advantage towards the knee joint. It is when the load been transmitted across the joint in order to give maximal congruency towards the joint. This study will focuses on two objectives which are to observe the effects towards the knee joint which having various cases of meniscus and also to observe the functionality of the meniscus which is wedges in shape. The method used in this study is a simulation of knee joint which is consisting of three main parts, femur, tibia and meniscus. In order to observe what the effects towards the knee joint, various cases is being simulated which are knee joint with healthy meniscus compared with knee joint with various of torn meniscus and a simulation of full leg with and without knee pad with existence of external impact. The boundary condition of force parameter is calculated from the ball velocity after being kicked where the comparison between the two types of kicking result with instep kicking got high impact force and distributed force than inside kicking. The highest distributed force then is used for the simulation. Simulation result shows that a healthy meniscus transmits load across the joint in a uniform state within the range of 0.3 MPa and 0.4MPa. For torn meniscus, the result shows that it is failed to transmit the load across the joint. Thus an excessive stress is recorded across the surface of the tibia. The highest stress recorded is 0.5 MPa. For second simulation, 1000 N is used as an external force exerted to the leg surface. Result shows that the external force applied on the surface of the leg will give an effect towards the internal part of the knee joint where causing the knee joint to bend and meniscus to be compressed. Comparison between the full leg with and without knee pad shows that full leg without knee pad is having large of knee joint bending and meniscus be compressed more than full leg with knee pad. From these to simulation, an observation can be made where the placement of the meniscus between the femur and tibia is to maintain the congruency between the bones and to prevent an excessive stress happen to the joint.

ABSTRAK

Meniskus merupakan sesuatu yang penting terhadap lutut manusia. Tempat di mana meniscus berada memberi kelebihan kepada lutut manusia Hal ini demikian kerana apabila beban melalui sendi lutut manusia, beban tersebut akan disebarkan terus ke permukaan tulang sendi. Ini membuatkan sendi lutut manusia dalam keadaan yg selesa tanpa tekanan berlebihan. Objektif utama projek ini adalah untuk mengenalpasti kesan yang berlaku tehadap sendi lutut di dalam dua keadaan iaitu sendi lutut yg mempunyai meniskus yang sihat dan juga sendi lutut yang mempunyai meniskus yang koyak. Di samping itu juga, objektif projek ini adalah untuk melihat keberkesanan bentuk meniskus di antara dua tulang penting iaitu tulang peha dan juga tulang kering. Bagi melihat kepentingan meniskus dan apa kesan yang terjadi terhadap meniskus, simulasi dilakukan. Reka bentuk lutut yang dibuat mengandungi 3 komponen iaitu tulang paha, tulang kering dan juga meniskus. Simulasi yang berlainan juga dilakukan di mana kaki lengkap bersama penutup lutut dan juga kaki lengkap tanpa penutup lutut dengan kehadiran beban dari luar. Simulasi pertama dilakukan dengan menggunakan beban yang dikira daripada kelajuan bola selepas disepak di mana perbandingan di antara dua jenis sepakan. Keputusan menunjukkan sepakan jenis ‘instep’ mempunyai beban yang tinggi dan juga sebaran beban yang tinggi. Sebaran beban yang tertinggi akan digunakan untuk melaksanakan simulasi. Keputusan simulasi menunjukkan meniskus yang sihat menghantar beban secara seragam di dalam lingkungan 0.3MPa sehingga 0.4 MPa untuk setiap nodus di atas tulang kering. Bagi simulasi lutut dengan meniskus yang koyak, keputusan simulasi menunjukkan meniskus gagal untuk menghantar beban secara seragam di mana ada tekanan yang tinggi di beberapa nodus. Tekanan tertinggi direkodkan adalah sebanyak 0.5 MPa. Bagi simulasi kedua, 1000 N beban digunakan untuk ditujukan kepada permukaan lutut. Keputusan menunjukkan beban dari luar tetap memberi kesan terhadap bahagian dalam lutut. Kesan yang berlaku menyebabkan lutut bengkok dan meniskus ditekan sehingga berlaku perubahan bentuk meniskus. Perbandingan di antara kaki lengkap bersama penutup lutut dan tanpa penutup lutut menunjukkan penutup lutut berupaya mengelakkan lutut bengkok secara maksimum dan perubahan yang banyak terhadap bentuk meniskus. Bagi kedua-dua simulasi yang dilakukan, satu pemerhatian boleh dilakukan di mana meniskus yang berada di anta dua tulang adalah untuk memastikan kedua-dua tulang tersebut di dalam keadaan yang selesa tanpa kehadiran tekanan yang tinggi berlaku .

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E	Young’s modulus elasticity
a	Acceleration
ϵ	Strain
σ	Stress
m	Mass
v	Velocity
t	Time
F	Force
ρ	Density
%	Percentage

LIST OF ABBREVIATIONS

ANSYS	Analysis of System
3D	3 Dimensional
UMP	University Malaysia Pahang
FEA	Finite Element Analysis
MRI	Magnetic Resonance Imaging

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Human knee is one of the largest and complicated joint that placed between the thigh and shank. All movement that related to leg will be restricted if the knee is injured. That shows how important is the knee towards our body in term of motion. The upper leg bone (femur), lower leg bone (tibia), meniscus, cartilages and ligaments are the important parts of knee joint. In this study, ligaments and cartilage will be ignored and stress more on femur, tibia and the meniscus.

Soccer is one of the sport activities that got many impressions throughout the world. The popularity of the sport itself is depends on the player's popularity in term of his skill and ability. On the part of his skills and ability, there is biomechanics that work on his body. This biomechanics can be divided into many parts such as on the foot which is used to kick the ball, on the head which is used to heading the ball and so on. In this study, the focus will be more on the knee joint in order to see the effect of knee meniscus that located between the joint while player kicking the soccer ball.

Meniscus is one of the parts that consist on human knee joint located between the joint of femur and tibia. Meniscus has always been loaded by an axial force either from the upper part of the body or the lower part of the body. It is a fact that, a body that being loaded continuously will get defect. It is same goes to the meniscus. Common meniscus disorders are the meniscal tears. It is the result of stresses that act through the meniscus body. In this study, we will see the effect towards meniscus during soccer kicking in term of its movement and its stress distribution.

1.2 PROBLEM STATEMENT

Knee is a part of the body that located between thigh and shank is one of the most complicated and largest joint in human body. The knee has to support nearly the whole of human's weight, so that it is easy for the knee to get injured. The common injuries that occur are ligaments, meniscus or bone fracture which are internal part of the knee.

"Most injuries that occur in the knee either cause meniscal damage or are the function of previously damaged meniscus, a complex tissue that has been historically underappreciated." (Fening, 2005)

For soccer games, knee is the most critical part that will easily get injured due to the shock from an external impact. Torn meniscus is one of the effects. This study will learn about the effect towards the knee joint having healthy meniscus compared with the different types of torn meniscus within the joint.

"Most of the tears (73%) occurred in athletes who were soccer player, basketball players, or skiers. The medial meniscus was torn more frequently than the lateral which is 70% of the tears in the study was medial" (Knee Injuries, 2012)

From the statistic, it is shows that the meniscal tear is the common disorder that act towards the knee meniscus. The common factors are from the knee twisting and pivoting but it is also may come from the force distributed from the feet towards the knee joint. In this study, we want to see the effects that happen towards the meniscus when someone kicking the ball.

1.3 OBJECTIVE

The objectives of this project are to predict the effect towards the knee joint with the healthy meniscus compared with knee joint with different type of torn meniscus and to observe meniscus properties which are its wedges shape.

1.4 SCOPES

The scopes of this project are as follows:

1. Limited to 3D modeling of knee joint consist of femur, tibia and meniscus.
2. Study on stress reading on the surface of the tibia.
3. Study on two types of kicking which are inside kick and instep kick.
4. Study the effect of meniscus by simulating full leg with and without knee pad.

1.5 ORGANIZATION OF THESIS

In this thesis, it is consisting of five chapters where chapter 1 is focuses on the background of the study, the problem statement, objectives and scopes. Chapter 2 is focuses on the summary of journals where several topics will be discussed regarding the study. Out of 15 journals, 5 topics are listed out. Chapter 3 is discussing on the flow of the project from the beginning till the end. In addition, the method used in this study will also be discussed in this chapter. Chapter 4 is focuses on the result of the study. The result will be discussed on how and why this happen in orders to get the conclusion of the study. Last but not least, Chapter 5 is a part where the conclusion of the study will be discussed and several recommendations for future use.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, the basic knowledge which related to the human knee joint will be described in it. A simple explanation and introduction to the femur, tibia and meniscus will be defined. There will be three topics that will be discussed regarding the knee meniscus in this chapter which are meniscal function, meniscal movement, the common meniscus disorder. Last but not least, an explanation that related to the soccer which is instep kicking and inside kicking will be explained. Some journal and article which are highly related to this study will be summarized.

2.2 FEMUR BONE

The femur is the longest and strongest bone in the skeleton is the most closest to the center of the body. Femur is said to be 26% of the person height since it is the longest bone. Two femurs is converge towards the knee and end at the upper surface of the tibia. Femur is the main bone that remote all the movement since it is the connecter between the bottom of the body and the hip. Figure 2.1 shows the knee anatomy consisting of femur. (Knee Anatomy, 2013)

2.3 TIBIA BONE

The tibia or the other name is shin bone o shank bone is the two bones that located below the knee. The upper part of the tibia is consisting of two flat-topped that articulate with upper bone which is femur. Tibia also is the connector between the knee and the ankle bone. Tibia is recognized as the strongest weight bearing bone of the body. Figure 2.1 shows the knee anatomy consisting of tibia. (Knee Anatomy, 2013)

2.4 KNEE MENISCUS

Meniscus of the knee is a complex structure that can be found within each knee between the upper leg bone, femur and lower leg bone, tibia. The study about the knee meniscus will enhanced the understanding of its function and its roles towards human body. (McDermott *et al.*, 2008)

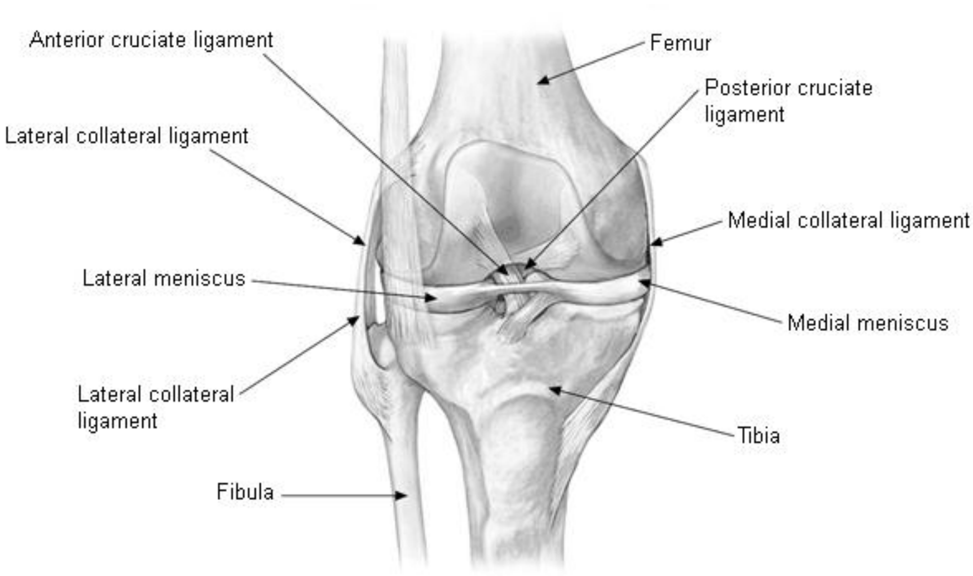


Figure 2.1: Human right knee anatomy

Source: Human Knee Anatomy (2012)

2.4.1 Medial Meniscus

Medial meniscus which is semilunar in shape is larger than the lateral meniscus. The capsular and bony attachments of the medial meniscus constrain its motion, possibly accounting for the higher frequency of injury. (Lee *et al.*, 2000)

2.4.2 Lateral Meniscus

The lateral meniscus is more circular in shape and the dimension of the posterior and anterior is the same. Lateral meniscus is covering more surface area of tibia because of its more circular in shape. (Lee *et al.*, 2000)

2.5 SUMMARY OF JOURNALS

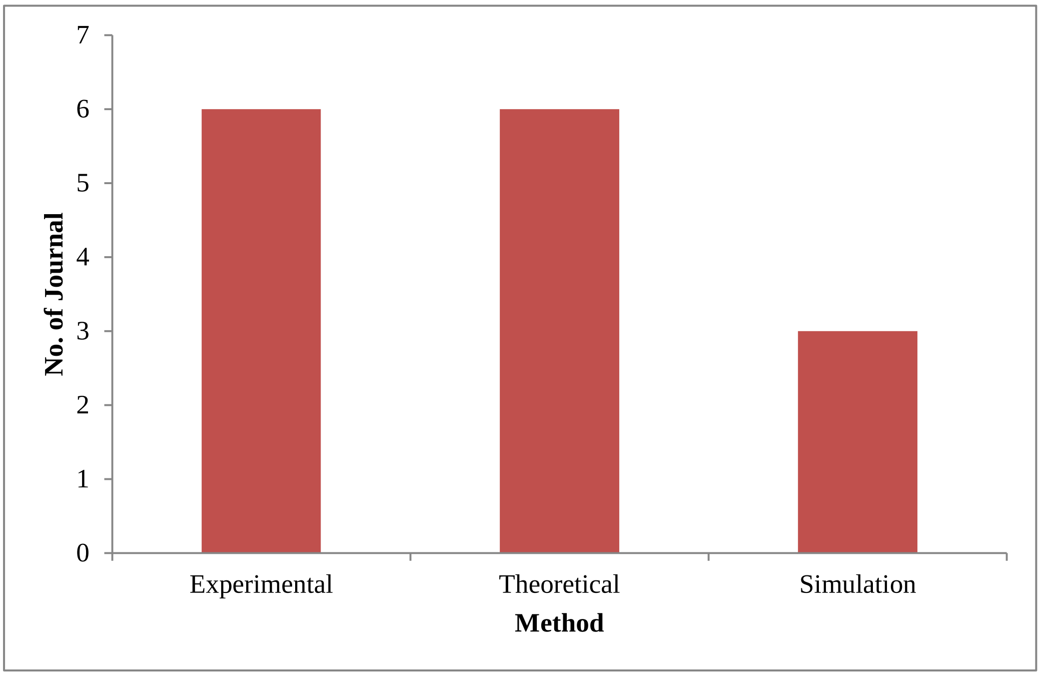


Figure 2.2: Method of journal

Fifteen of journals have been reviewed and each of the journals is using difference kind of method. Three methods is been classified which are experimental, theoretical and simulation. Experimental method is where the author is using an experimental approach to do the project. Theoretical approach is where the author is discussed the topic throughout his project and lastly the simulation method is where the author simulating the design in order to get the result. From the Figure 2.2, it is stated that out of 15 journals, 6 journals is using the experimental and theoretical method and 3 methods is using simulation approach. The list of journals used can be seen in Table B-1 in Appendix B.

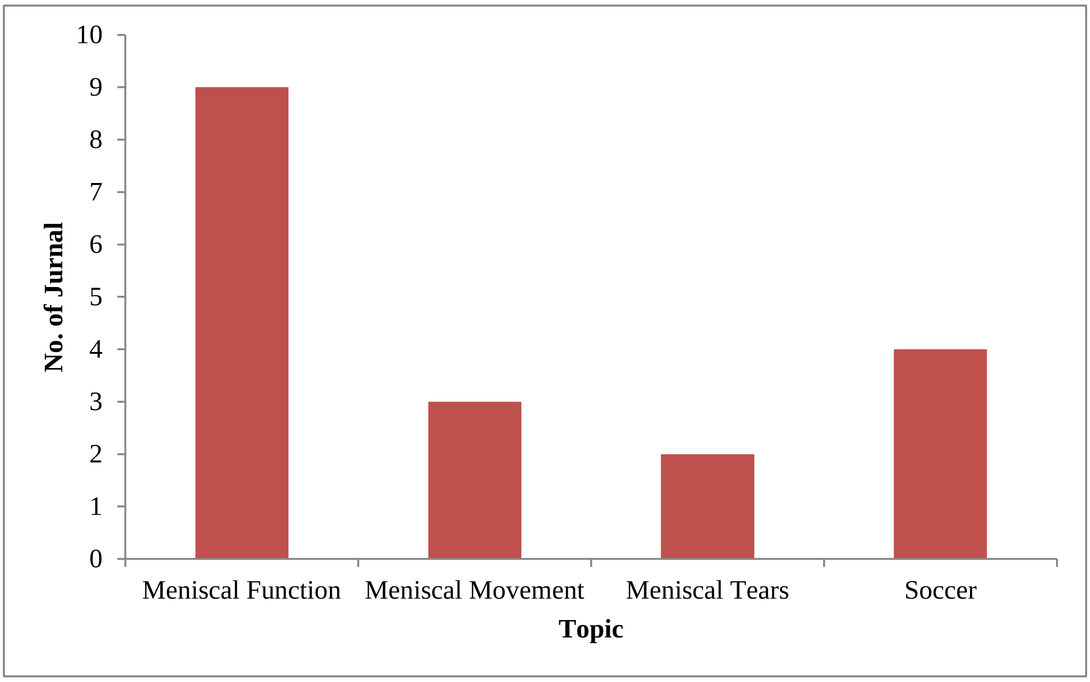


Figure 2.3: Topic of journal

Fifteen of journals have been reviewed that discussed about the general view of meniscus and regarding the soccer. Three topics will be discussed deeply about the meniscus which are meniscal function, meniscal movement, meniscal tears, and other three topics regarding the soccer which are Soccer Disease, Instep Kick and Inside Kick.

2.5.1 Meniscal Function

Meniscus is an internal part of the body that found between the femoral condyles and tibial plateau. There are two types of meniscus within the knee joint, which are medial and lateral. These two crescent shape cartilages is a fibro cartilageous structure, which is made up from a network of collagen fibres. The meniscus is one of the complex structures that having various function towards the human body. The function of the meniscus is been discussed a lot by researchers in their literature. The meniscus acts an important role towards the knee in order to protect the joint between the femur and tibia. The main function of meniscus is to distribute the load across the joint between femur and tibia. Other than that, meniscus is also act as stabilizer between the joint, joint lubrication and so on. Many literatures discussed about its main function that is load transmission. By distributing the load across the joint, this will ensure the stability of the joint. This will result the stress experienced by the joint been decreased. Figure 2.4 shows the different between the knee with meniscus and without meniscus.

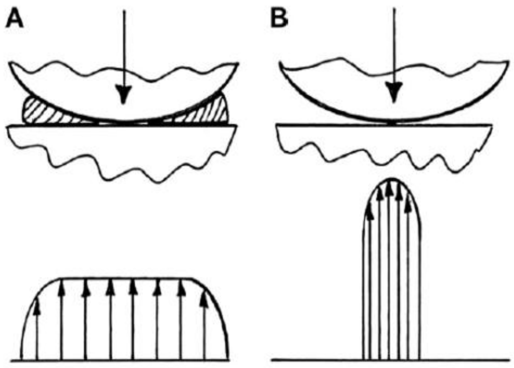


Figure 2.4: Differences between the knee with meniscus and without meniscus

Source: McDermott *et al.* (2008)

The common description of the meniscus is that they are semi-lunar fibrocartilagenous disks, whose main function is to increase the congruency of the tibiofemoral joint, thereby decreasing the stress in the joint through an increase in the contact area. (McDermott *et al.*, 2008). Since the meniscus is a viscoelastic material, it will tend to compress when the load is applied. As the femur and tibia is moving, the meniscus is also will move, so that the congruency of the joint can be maintained. When the meniscus move from its original shape, it shows that force is being transferred across the meniscus body. This is called the hoop stresses that act within the meniscus body. The compression force across the knee, as it is transmitted from the femur through the meniscus to the tibia, causes tension along the circumferential collagen fibres within the meniscal tissues. (McDermott *et al.*, 2008)

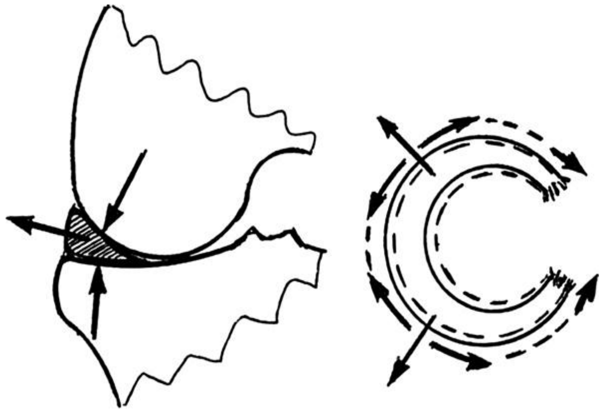


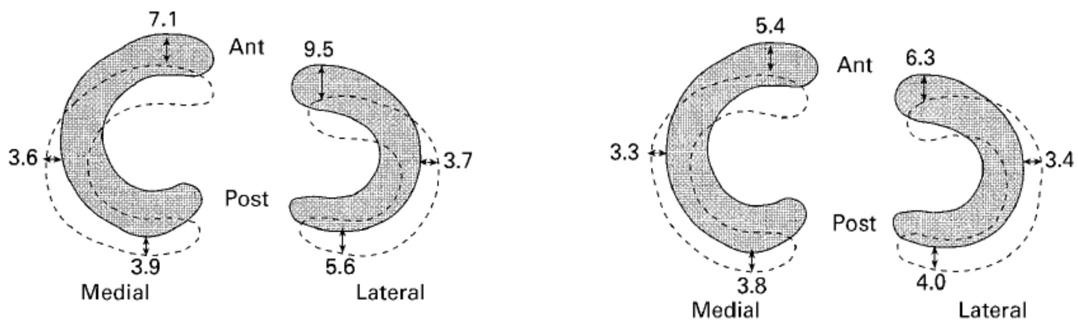
Figure 2.5: Conversion of axial load into meniscal hoop stresses.
Source: McDermott *et al.* (2008)

McDermott *et al.* (2008) stated in the literature regarding the development of hoop stress within the meniscus body, it is a result from a net resultant force that generated when load is applied. The wedge shape of meniscus after being loaded will make it to extrude from its original shape and creates a more congruent surfaces between the femur and tibia. Therefore, the transmitted and distributed load that across the upper or lower bone will over the large surface area. In order to prevent the meniscus from extrude more, hoop stresses is developed. Compression force that act towards thee knee joint will cause the meniscus to move and change in shape. Movement of the meniscus during knee flexion ensures maximal congruency with the articulating surfaces while avoiding injury to it. Dynamic congruity facilitates load transmission, stability, and lubrication. (Vedi *et al.*, 1999)

2.5.2 Meniscal Movement

Meniscus of the knee is having viscoelastic properties that are described as a combination or mixture of solid and also fluid components. Viscoelastic and elastic has their own properties. For elastic material, Viscoelastic and elastic material is having a different meaning and properties. In an elastic material, the energy used to deform the material is equal to the integral of the force deformation curve. (Andrews *et al.*, 2011). That is mean, when loading and unloading process; there will be no energy loss or any energy absorption. This is opposite with the viscoelastic condition. When loading and unloading process, the energy between those two works will not the same. The energy loss phenomenon is due to the movement of fluid and/or the rearranging of molecule structure of the tissue itself. (Andrews *et al.*, 2011)

Since the meniscus is having fluid structure in its cross section, the meniscal water content could be extruded either by compression or by direct application of a pressure differential. (McDermott *et al.*, 2008). This will result with the displacement or deformation of meniscus that is to maintain the congruency of the femur and tibia joint, hence, the meniscus will carry about 40% to 70% of the load across knee. (Vedi *et al.*, 1999). When load is applied, force distribution will go through the femur and the meniscus will experienced the force. The fluid components of meniscus will slowly to extrude depends on its permeability and the viscosity of fluid. Vedi *et al.* have done experimental setup by testing subject's knee joint to determine the meniscal movement through an arc of flexion-extension while weight bearing. The result state that the menisci do move posteriorly as the knee flexes and the lateral meniscus did move more compared to the medial meniscus. (Vedi *et al.*, 1999)



a) b)

Figure 2.6: Mean movement in each meniscus a) weight bearing b) unload knee

Source: Vedi *et al.* (1999)

From the results, it shows that the movement of the meniscus during the knee-flexion is to ensure the maximum congruency of the joint and also the articulating surfaces in order to avoid it from injury when having load. The result also state that the lateral meniscus did move more than medial meniscus. This is because there is no attachment between the lateral meniscus to any ligament compared with medial meniscus which attached to the medial collateral ligament. That is why the mobility of medial meniscus is restricted compared with the lateral meniscus which moves more when being loaded or flexion-extension happens.

2.5.3 Meniscal Tears

Knee meniscus is a two semicircular pad that can be found between the joint of upper leg bone (femur) and lower leg bone (tibia). It is become the function of meniscus to be an effective load transmission, so that the joint congruency can be enhanced. All material that is continuously loaded will have defect on its body. Same goes with the meniscus. The common defects that always occur are meniscus tear. Meniscal tears can happen to everyone without notice. Whether the age is young or old, everybody have a chance to get it depends on their lifestyle. At the young age, meniscal tears are caused by trauma in which happen while they are doing activity. In case, their knee is pivoted or twisted while they are doing activity, the meniscus can be torn. For old age, meniscus tears are a common thing for them. It is because the fluid structure within the meniscus will degenerate as their age is increased (Meniscus Disorder, 2012)

There are many types of meniscus tears that can be classified. Meniscal tears can be classified according to their location, shape, size, and stability. The classified tears are vertical longitudinal, oblique or called as parrot beaked, displace or called bucket handle, degenerative, transverse, horizontal or complex. Out of those tears, the most common tears that always occur are vertical longitudinal and the oblique tears. About 81% of the meniscus tears are parrot beak or longitudinal tears affecting more often the medial meniscus. (Pena *et al.*, 2005). Figure 2.7 shows a certain pattern of tears that happen at the knee meniscus.

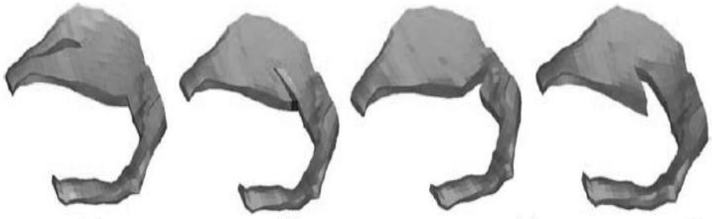


Figure 2.7: Patterns of meniscal tear: a) longitudinal b) oblique c) transverse d) parrot beak.

Source: Pena *et al.* (2005)

Once the meniscus torn, surgical is the best way to prevent any compilation happens towards the knee joint. If not, the continuous knee motion and continuous load applied towards the meniscus can worsen the original tear. The surgical way that is one of the best is meniscectomy. Meniscectomy is a step to alter the shape of meniscus or remove the tear part of the meniscus. There are also different types of meniscectomy which are longitudinal, radial, oblique and total. After meniscectomy is done towards the torn meniscus, it will result with effect towards the joint of femur and tibia. Meniscectomy dramatically alter the pattern of static load transmission of the knee joint. (Pena *et al.*, 2005). This is because the fluid structure within the meniscus is being altered and the way of meniscus distributing the load will be different with the healthy meniscus. Hoop stresses are lost when a radial tear occurs or a segmental meniscectomy is performed; the load bearing condition become similar to that after meniscectomy. (Lee *et al.*, 2000). Figure 2.8 shows a difference of load distributing between a healthy meniscus and also meniscus after meniscectomy.

a)

b)

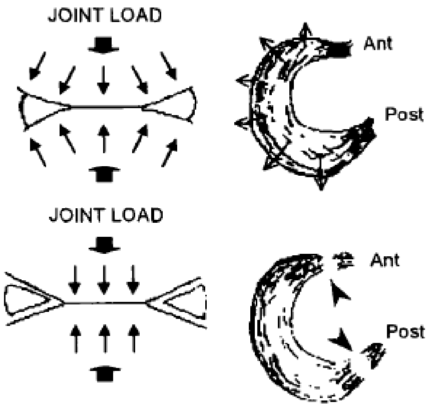


Figure 2.8: Difference of load distributing a) healthy meniscus b) meniscus after meniscectomy

Source: Lee and Fu (2000)

The torn meniscus has to be treated as soon as the symptom is showed. The symptom of torn meniscus can be seen physically. The knee will swell if the meniscus is tearing. Once the knee joint is in motion, there will be popping or clicking sound within the knee. The patient unable to extend his leg comfortably and when flexion, it is the better way to reduce the pain. The motion of the leg will be limited. That is why torn meniscus has to be treated as soon as possible. Once the meniscus is torn, the possibility for the patient to get knee arthritis is higher. It is because there will be excessive stress towards the joint and the articular cartilage cannot be protected.

Out of four types of meniscectomy, the total meniscectomy is the least type that applied in the surgery. This is because the effect afterwards is worse than others. Total meniscectomy will result with articular wear after a certain years. This is because there is one missing meniscus after the total meniscectomy. Several researchers have reported higher stresses and a decrease in shock absorbing capability after total meniscectomy (Pena *et al.,* 2005). That shows the important of meniscus as a load transmission between the joint.

After the meniscectomy, the rehabilitation program is important so that the healing process is smoothly done. Forces that occur during knee motion potentially could distract the meniscal repair and disrupt healing. (Richards *et al.*, 2008). Basically, the meniscal repair should aim to maintain the structure of the meniscus which is circumferential. This is to maintain the function of meniscus which is load transmission so that the joint surface is not subjected to the excessive stresses.

2.5.4 Soccer Disease

Soccer activity and injury is a common combination that been discussed a lot. It is because; soccer is an activity that will use all of our human body part from head to toe. Figure 2.9 shows the percentage of injury breakdown by body part for soccer kicking.

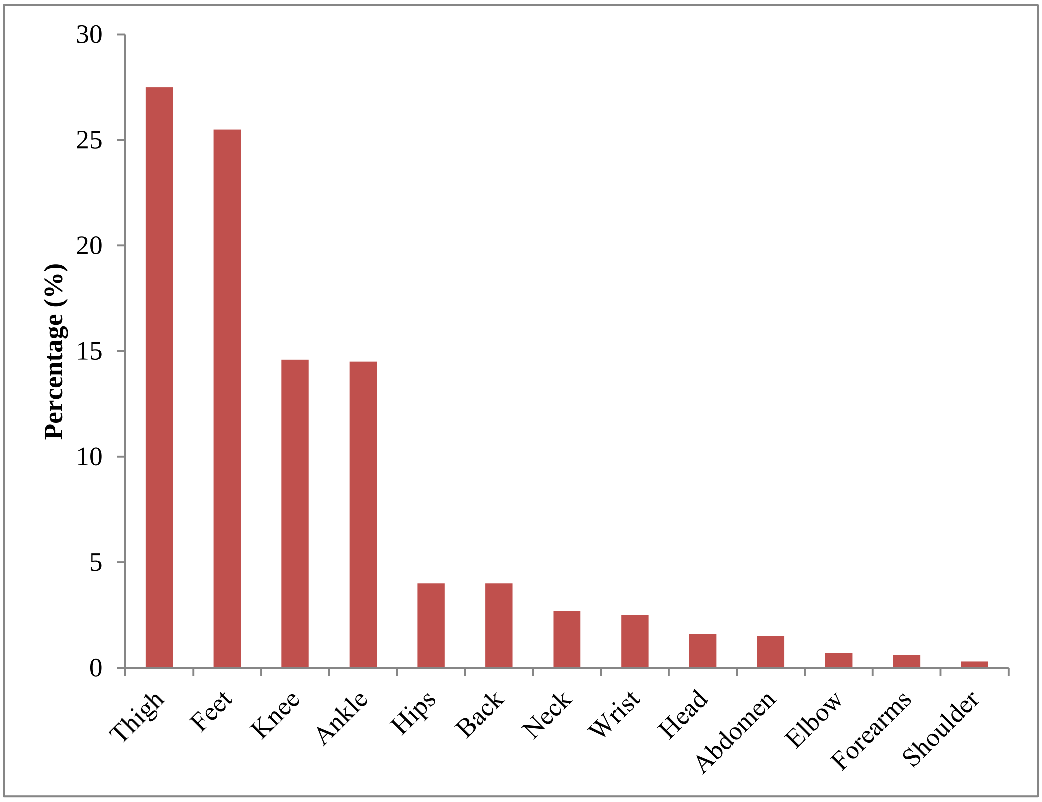


Figure 2.9: Percentage of injury breakdown by body parts for soccer game

Source: Common Soccer Injuries (2012)

Based on the figure above, it is represented the percentage of injury breakdown by body part for soccer game. There are thirteen body parts that may be injured while playing the soccer game which are thigh, feet, knees, ankles, hips, back, neck, wrists, head, abdomen, elbow, forearms and lastly is shoulders. The factor that may cause the injury may come from external impact towards the body part or from the pivoting or twisting of body parts. From what being discussed in this paper, which is the knee, it is the part that becomes top three commonly injured in a soccer game with 14.6%. It is proven that the knee is a part that can injured easily while player is playing the soccer.

Most of the tears (73%) occurred in athletes who were soccer player, basketball players, or skiers (Knee Injuries, 2012). That is the statistic that shows the meniscus that located within the knee joint is torn commonly for an athlete. In addition, medial meniscal injuries are often also associated with injuries to the anterior cruciate ligament (ACL) and the Medial collateral ligament (MCL) that is the most common diseases for athletes.

2.5.5 Instep Kicking

Most of the literature regarding the soccer is discussed more on instep kick which is the common kick that player use in a soccer game. Instep kick also has become the most widely studied for a soccer kicking. (Ismail *et al.*, 2010). A study about the kicking technique can be important if we want to enhance our understanding regarding the biomechanics of soccer. Other than that, by studying about the biomechanics of kicking, coaching process can be assisted. (Ismail *et al.*, 2010).

As been discussed by a lot of researchers about the instep kicking, there are a few factors that can ensure the successful of that kicking which are distance of the kick from the ball, type of kick used, the air resistance and also the technique used. All of these can be taken as a biomechanical analysis. Other than the factors above, the foot to ball interaction is also important. This is including the speed of feet before the kicking is done. The higher the speed of the foot before impact, the shorter the foot-ball contact and the highest the ball speed. (Ismail *et al.*, 2010). Figure 2.10 shows the kinematic of instep kicking.

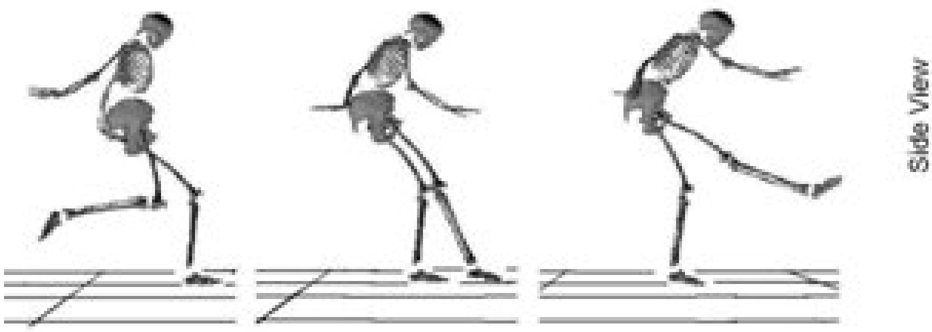


Figure 2.10: Kinematic of Instep Kicking

Source: Kinematics of Instep Kick (2012)

The best output of instep kicking is depends on the highest velocity of ball after being kicked. In order to get the maximal velocity of ball after being kicked is by applying the highest velocity on the foot before the impact. Kicking with running approach demonstrates higher ball speed values compared with static approach kicks. This is because the velocity of the foot is increasing since the player applying running approach before kicking. Practically, players prefer to have multi-step approach before doing a kicking. (Ismail *et al.*, 2010).

2.5.6 Inside Kicking

The foot area used to do inside kick is the area between the big toe and the ankle. It is different with the instep kick which rely on the upper surface of the foot. The purpose of this kick is also different. The output of the inside kick will result with low velocity of the ball after the impact difference with the instep kick which result with high velocity of ball. Inside kicking is the most kick that players use while they in their games. By using inside kick, it allows the players to send a highly accurate short pass to their teammate. Players use this inside kick estimated around 70 percent of the game. (Inside Kick, 2013). Figure 2.11 shows the example of foot position while doing inside kick.

Figure 2.11: Foot position for Inside Kicking
Source: Kicking Experiment MSNT

2.6 ENGINEERING FUNDAMENTAL THEORY

2.6.1 Newton's Second Law of Motion

In Newton's second law of motion, it could explain by using Equation (2.1). The acceleration produced when the body hit by a force is directly proportional to the magnitude of the force for a constant mass object.

$$\text{Force} = \text{mass} \times \text{acceleration} = \text{ma} \tag{2.1}$$

The value of acceleration is got from the change of velocity in time. It can be referred as Equation (2.2)

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}} = \frac{\text{v}}{\text{t}} \tag{2.2}$$

The formula above is used for defining the force that will react and been distributed towards the knee joint. Equation 2.2 is used by applying the value of velocity of foot that taken from the journal and minimum time between the impacts of foot to the ball. Hence, the acceleration can be achieved. Then, by applying the value of acceleration and mass of the ball into Equation 2.1, we can get the value of force that experience by the foot and the ball.

2.6.2 Newton’s Third Law of Motion

In Newton’s third law of motion, it is stated that every force is balanced by an equal but opposite force. In this study, the same amount of force would be acting on the player’s leg as well as on the ball. The force between the foot and the ball will be transmitted directly towards the leg and to the knee.

2.6.3 Stress and Strains

Stress and strains are the common terms in engineering. Stress can be defined as the force that acting towards the body at certain area in all direction. While strain can be defined as the rate of change of deformation or displacement related to the original dimension when being loaded. Stress and strain could be explained by Equations (2.3) and (2.4)

$$\text{Stress}, \sigma = \frac{\text{Load}}{\text{Cross sectional area}} = \frac{P}{A} \quad (2.3)$$

$$\text{Strain}, \varepsilon = \frac{\text{Change in length}}{\text{Original length}} = \frac{\delta l}{l} \quad (2.4)$$

The formulas above will be used in the simulation phase. For the stress formula, it is shown in the stress distribution that will act across the meniscus after being loaded. The force applied will result a difference force distribution respect to the area of meniscus body. For the strain formula, the result will show the dimensionless number. It is defined as change in length over initial length. The change in length will result from the displacement of meniscus after the load is applied.

2.7 BOUNDARY CONDITION

Boundary condition plays an important role in many applications. The tibia and femur will be considered to be rigid bodies. (Vedi *et al.*, 1999).The meniscus will be located between the femur and tibia. The material properties of each part which are femur, tibia and meniscus were selected from the data available in the other literature.

The selected leg for kicking the ball will be a dominant leg in order to get the maximal speed of leg of the kicker. The arrangement of each part will be femur, meniscus and tibia. A mechanical load will be applied at the bottom of the tibia as there is no force imitates the human load at the top of the femur. All the force that imitates the human load will be directed towards the other leg of the kicker as the dominant leg is not touching the ground when kicking.

2.8 SIMULATION STUDY

Previous research has shown by using the simulation and experimental process. The prediction of effect towards meniscus after being loaded from a force distribution that acts through the bone can be made. Table 2.1 shows the summaries of previous study for determining the effect towards the meniscus and also the study about the instep kicks.

Table 2.1: Journal summaries for determining the effect towards meniscus and the study about the Soccer

Journal	Results
Niu and Wang (2012)	Meniscus which is the physical connection between the femur and the tibia is functioning as shock absorber. The stress distribution that acts through the meniscus is concentrated in their frontal area.

Table 2.1: Journal summaries for determining the effect towards meniscus and the study about the Soccer (Continued)

Pena *et al.* (2005)	Meniscus transferred about 81% of the total load. The contact pressure and stresses is slightly higher at the medial meniscus.
Vedi *et al.* (1999)	The anterior part of the meniscus is more mobile than the posterior part. The lateral meniscus is more mobile than the medial meniscus.
Ismail *et al.* (2010)	Applying running approach before the kicking step will result with the highest speed of foot and maximum force towards the ball.
Dorge *et al.* (2001)	The linear speed of the foot and the ball will be higher when kicking with the preferred leg compared to the non-preferred leg.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter discussed the method used in this study. By modeling and simulating of the dominant leg of a human’s knee, which is included the upper leg bone (femur), lower leg bone (tibia) and also the meniscus. The dimension of these parts are used in the modeling were referred to the human’s knee model. Besides, the parameters used to setup the simulation of the complete structure were based on the literature reviewed in Chapter 2. The simulation was performed by using Ansys Static Structural.

3.2 EXPERIMENT SETUP

3.2.1 Design Concept of Human Knee

In the modeling part, three important parts which are femur, tibia and meniscus will be designed. The design of the parts is referring the dimension of human’s knee model which is owned by Centre of Sport and Engineering group, University Malaysia Pahang by using the Computer Aided Design (CAD) software which is SolidWork. The design of the three parts will be different for each part. The complete drawing for each part will be assembled by using the SolidWork software and will go through the simulation process.

There will be 3 different designs that will be used in order to do the simulation. This is because the result of simulation for each of the design will be different and average result will be used. The 3 different designs will consist with the same number of parts which are femur, tibia and also meniscus.

3.2.2 Parameter Setup

The parameter of the design's part is taken from the journal that been reviewed which are *"A Subject Specific Multibody Model of the Knee with Menisci"* by T.M. Guess, G. Thigarajan, M. Kia, and M. Mishra, and *"Finite Element Analysis of the Effect of Meniscal Tears and Meniscectomies on Human Knee Biomechanics"* by E. Pena, B. Calvo, M.A. Martinez D. Palanca and M. Doblare The parameter of the meniscus, femur and tibia is tabulated in Table 3.1.

The parameter for the Instep and Inside Kicking is taken from the result of experiment that used 3 athletes from Majlis Sukan Negeri Terengganu (MSNT) as a subject. The subject has to kick the ball by using Instep and Inside Kicking with 3 numbers of trials. The result used for this project is the ball velocity after the impact between the foot and the ball. Table 3.2 and 3.3 shows the result of the kicking experiment for both types of kicking which is instep and inside kicking.

Table 3.1: The parameter of the meniscus, femur and tibia

	Parameter	**Value**
Meniscus	Density	1100 kg/m3
	Young's Modulus	59 MPa
	Poisson Ratio	0.49
Femur	Density	1600 kg/m3
	Young's Modulus	20000 MPa
	Poisson Ratio	0.2
Tibia	Young's Modulus	14000 MPa
	Poisson Ratio	0.315

Source: Guess et al (2010), Pena et al (2005)

Table 3.2: The ball velocity after impact for Inside Kicking

Type of Kicking	**Inside Kicking**								
Subject		1			2			3	
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	15.54	14.19	15.12	16.95	18.35	16.89	19.09	19.53	21.11

Table 3.3: The ball velocity after impact for Instep Kicking

Type of Kicking	**Instep Kicking**								
Subject		1			2			3	
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	16.27	18.54	16.50	20.97	20.06	16.69	24.89	24.23	25.27

3.3 METHODOLOGY FLOWCHART

The project is started from a basic finding of information regarding the title from journals that related. By going through related journals, a summary regarding the 3 topics about the meniscus and also 2 topics about the kicking is done. The topics are meniscal function, meniscal movement, meniscal tears, instep kick and inside kicking. From the summary of journals, the objective, problem statement and the scopes is clear. Then, it continued to the study on how to perform the project by defining the methodology used. The parameter of the knee joint parts which are femur, tibia and meniscus were referred from the journals. The data for the ball velocity that used for the calculation method is taken from the result of experiment that used 3 athletes from Majlis Sukan Negeri Terengganu (MSNT) as subject with 3 trial of kicking each.

Next step will be modeling stage by using the CAD software which is SolidWork. Test simulation will be conducted so that the validation process could be defined. Besides that, the properties of the parts can be studied through the test simulation. After all the setup is analyzed, the simulation will be performed by using the Ansys Static Structural. The result and findings were collected and will be analyzed. Discussion and conclusion stage will take place as the result is valid. Finally, report writing and presentation will be performed in order to show the final result of the study

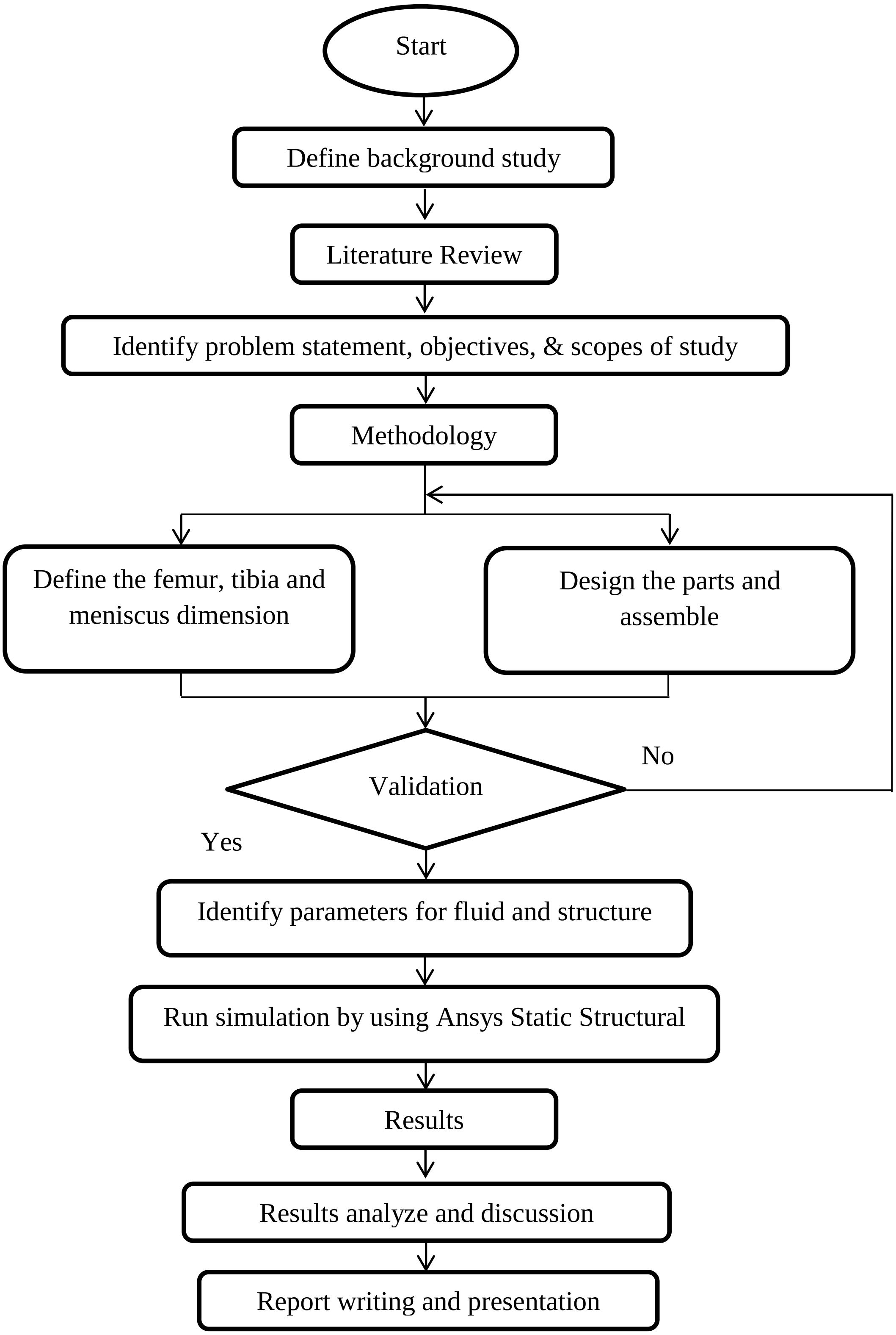


Figure 3.1: The Flow Chart of Project

3.4 CAD MODELING USING SOLIDWORK SOFTWARE

Modeling and analyzing the knee model that consists of upper leg bone (femur), lower leg bone (tibia) and meniscus are by using the Computer Aided Design (CAD) software. The dimension is taken from the human's knee model. The unit used while modeling the part is fixed to meter. This is because, while doing simulation, the step to setting up the parameter will use the Standard International (SI) units. There will be 3 designs of knee joint that will be used in the simulation process. The steps for making each design is the same but there is a bit of alteration for each design in order to make it difference with each other. Modeling of full leg consisting of skin, femur, tibia and meniscus is carried out. There will be two design of full leg which full leg with kneepad and also full leg without knee pad.

3.4.1 Modeling Flowchart

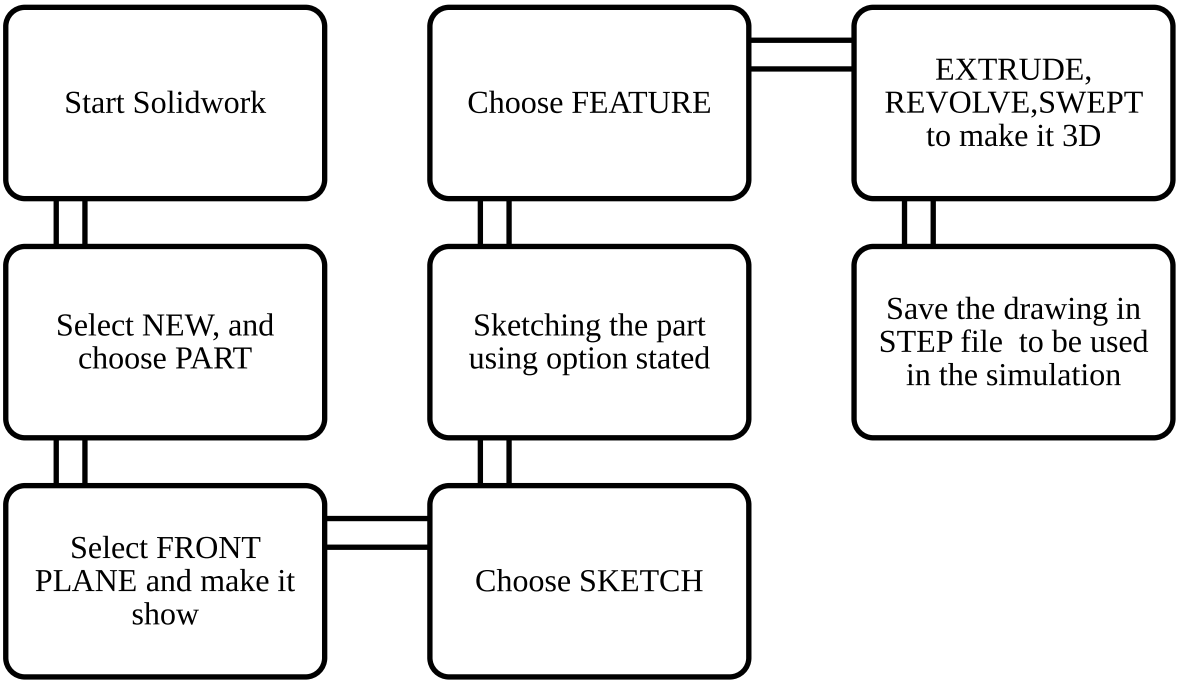


Figure 3.2: The flow process for modeling using the SolidWork software.

Flowchart above shows the overview steps to model the part using the CAD software which is SolidWork. For this project, SolidWork 2010 version is used. The very first step is opening the SolidWork software. Open the new part and select the plane to be viewed. Sketch the 2-dimensional form of the part by using the features in the SolidWork software. Once the sketching is done, using the features option, extrude the sketch to be the 3-dimensional model. Editing the model to ensure the model is fine in shape.

All the design for the simulation is assembled completely. The completed assembled part will be saved in STEP (*step) format so that the model can be imported to the Ansys Static Structural software. Table 3.4 shows the 3 designs that consist of femur, meniscus.

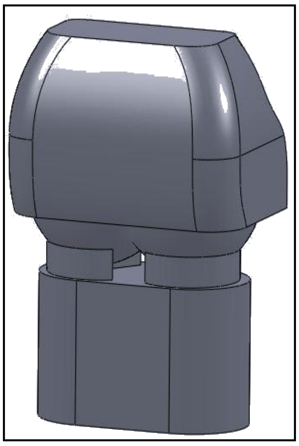
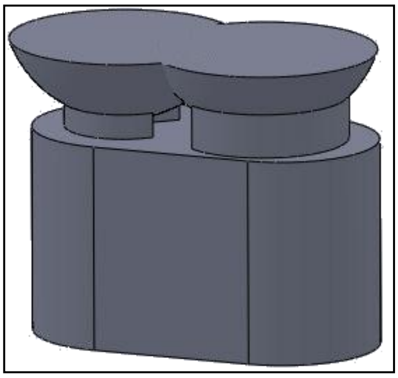
3.4.2 Modeling Healthy and Torn Meniscus

In the simulation process, the design that will be simulated is the knee joint with healthy meniscus compared with knee joint with torn meniscus. For the healthy meniscus, the surface of the meniscus is complete without any damage. Difference with the torn meniscus, there are 3 types of torn meniscus that will be used. First type is longitudinal tear where the specific type is bucket handle tear. Second type is flap tear which came from horizontal type of tear. The last tear is radial tear where the specific tear will be parrot beak tear. Four types of tear which are healthy and torn meniscus can be seen in the Table 3.5. For the simulation process, one meniscus on the left of knee joint design will change between the healthy and the tear meniscus. The result for each case will be different. The design of the meniscus will be wedges in shape followed the real one. There is also one simulation that will investigate regarding the wedges shape by comparing with the non-wedges meniscus.

3.4.3 Modeling of Full Leg With and Without Knee Pad

In the simulation process, there are two designs. One is for full leg with knee pad and the other one is full leg without knee pad. The design is consist of leg and the internal part which resemble of femur, tibia and meniscus. The internal part will be assembled inside the leg. In addition, for the leg with knee pad, a design of knee pad is attached towards the knee. The two designs of full leg with and without knee pad can be seen in the Table 3.6.

Table 3.4: Three designs of knee joint consist of femur, meniscus and tibia

Design	Modeling
Design 1	
Design 2	

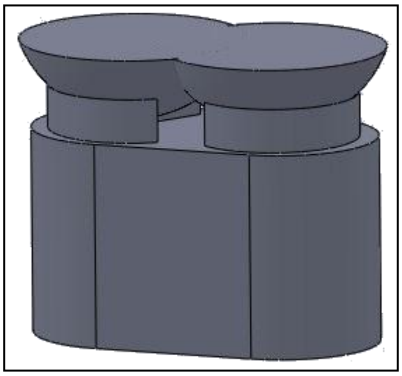
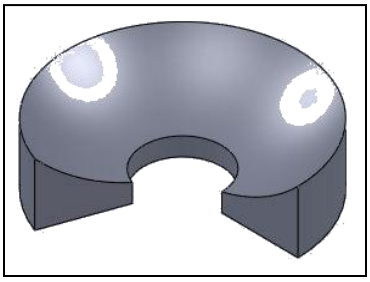
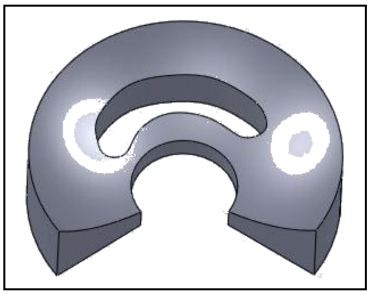
Design 3	

Table 3.5: Four designs of meniscus

Design	Modeling
Healthy Meniscus	
Bucket Handle Meniscus	

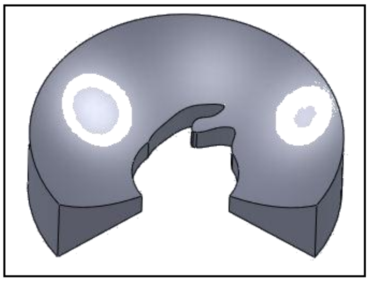
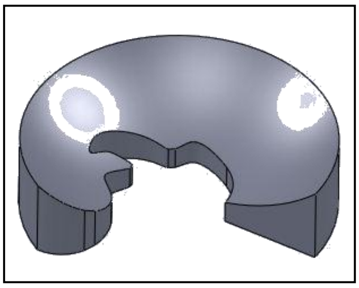
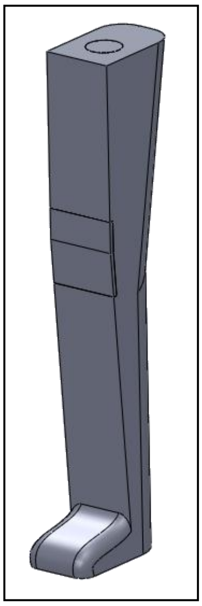
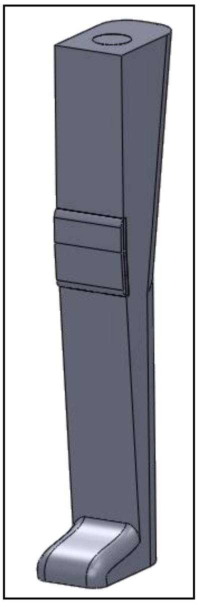
Flap Tear Meniscus	
Parrot Beak Meniscus	

Table 3.6: Two designs of full leg

Design	Modeling
Full Leg Without Knee Pad	

Full Leg With Knee Pad	

3.5 CALCULATION FOR SIMULATION

The result of kicking experiment involving instep and inside kick is tabulated in the Table 3.2 and 3.3 will be used for calculation method in order to find the distributed force parameter. The equations that will be used are Equation 2.1 and 2.2 where the impact force between the foot and the ball can be calculated. The calculated impact force is then be used to calculate the distributed force. For each type of kicking, there are various angles that related between the foot and the ball and the angle of leg while kicking. Figure 3.3 and 3.4 show the angles related for instep and inside kick.

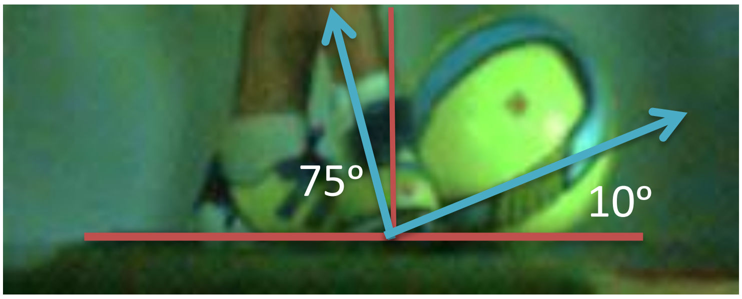
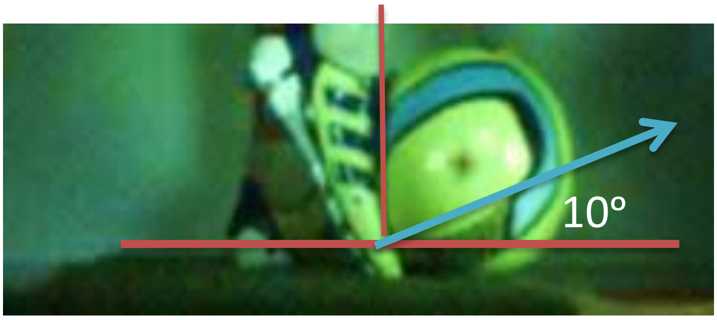
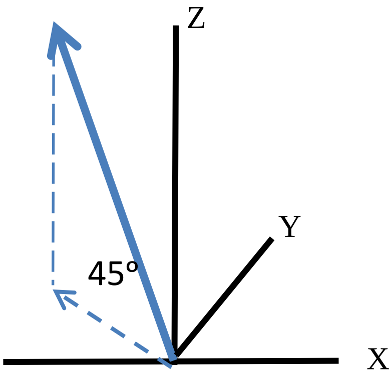
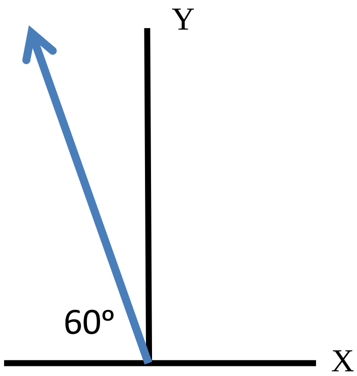


Figure 3.3: Angles related to Inside Kicking.



a)





b) c)

Figure 3.4: Angles related to Instep Kicking. a) Side view b) Front view c) Upper view

3.6 FINITE ELEMENT ANALYSIS

There are a lot of applications that can be solved by using of Finite Element Analysis software. By using this method, one can predict the behavior of a structure when it is being subjected to thermal or structural loads. The evaluation and the analysis of the simulation result can be done. The study of Finite Element will give us advantages regarding the structural and thermal problems. For this study, the simulation of knee joint will take place which consist of femur meniscus and also tibia. The expected result will show the effect and reaction that will occur towards the tibia of the knee joint with healthy meniscus, non-meniscus and torn meniscus. The completed model will go through the simulation process and been loaded with the similar distribution force from the impact between the foot and the ball after soccer kicking.

3.6.1 Pre-Setup Simulation of Knee Joint

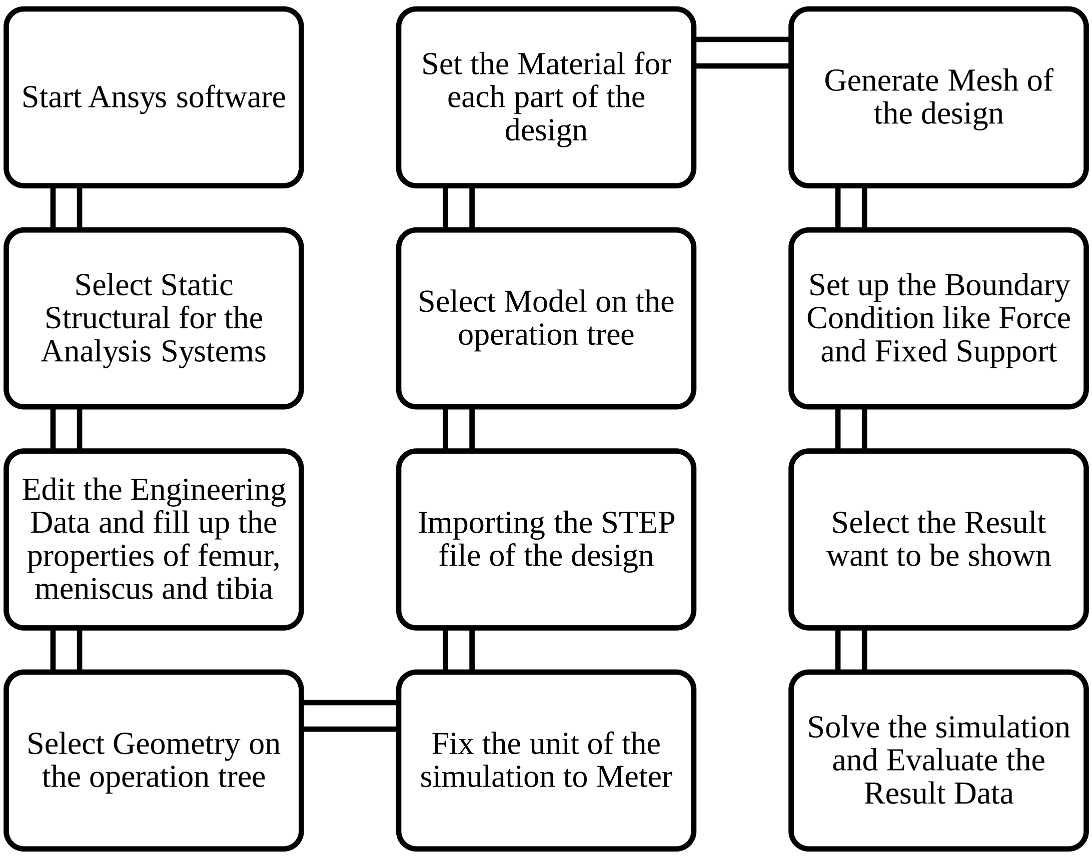


Figure 3.5: The flow process to setup in Ansys Static Structural for the Knee part

In the preparation for the simulation of the knee part, the steps were started with starting the Ansys software by double click the Ansys Workbench icon. Then, select the Static Structural as the Analysis Systems for the software. Wait till the operation tree come out. Right click on the Engineering Data and select Edit to fill up the properties of the design part which are femur, meniscus and tibia. On the operation tree, right click on the Geometry and select New Geometry, Design Modeler window will come out. Fix the unit of the simulation as SI unit, Meter. Start to import the STEP file of the design that being modeled by the CAD software. Click Generate on the taskbar in order to show the imported design. Check on the Tree outline which will show the number of part and the number of body included.

On the operation tree, right click on the Model and select Edit, Mechanical window will come out. Check the Geometry on the Outline Tree, each part of the design will be shown. Select a name of part on the Geometry, and match the Type of Material for that part. On the Outline Tree, Select Mesh. Detail of Mesh will be shown below. Set the Sizing Parameter of the mesh as shown like the figure. Then, right click on the mesh on the Outline Tree, select Generate Mesh. On the Outline Tree, right click on the Static Structural, select Insert and find Force in order to add up force parameter on the design. Detail of Force will be shown, On the Geometry under the Scope, select part on the design where force will be applied. Then, on the Define by dialog, set it as Components. We will set what values of force will be applied according to its axis.

Next Step is, right click on the Static Structural, select Insert and find Fixed Support. Select part on the design where fixed parameter will be applied. On the Outline Tree, right click on Solution, select Insert and find Stress. Set it as Equivalent (Von Mises). Right click on the Solution, select Solve. The simulation will run until it is done. All steps of the simulation can be reviewed from the appendix.

3.6.2 Simulation of Full Leg With and Without Kneepad

For the simulation process, Ansys Static Structural is used. The steps are all the same for the simulation of knee joint except for the design and additional of properties. For the simulation of full leg without knee pad, the force parameter is used 1000 N where it is applied towards the knee. For the simulation process of full leg with knee pad, the force is applied towards the surface of the knee pad where it is attached on the knee. The result of the simulation will be the effect that happen towards the internal part of the knee consists of femur, tibia and meniscus but the result will be focus on the meniscus in order to observe how the meniscus will react when an external force is applied.

3.7 NODES SELECTION

The node selection is for the simulation of knee joint consists of femur, tibia and meniscus. After the simulation is done, extraction data is needed in order to do the analysis and discussion purpose. The way to extract the data is by selecting critical nodes on the simulation result. For this purpose, nodes are selected on the surface of the tibia directly under the meniscus. Total of 10 nodes is used for the extraction data. The selection result will be Von Mises Stress where each node that selected will shows the value of stress reacts. The stress is exist after the force is applied through the tibia and cause the compression between the femur and the tibia. Each case will have different kind of result since the meniscus used that located between the femur and the tibia is different. Figure 3.6 shows the nodes selected on the tibia and the number for each node for graph plotting purposes. Figure below is the half of tibia where the node will be selected directly under the meniscus.

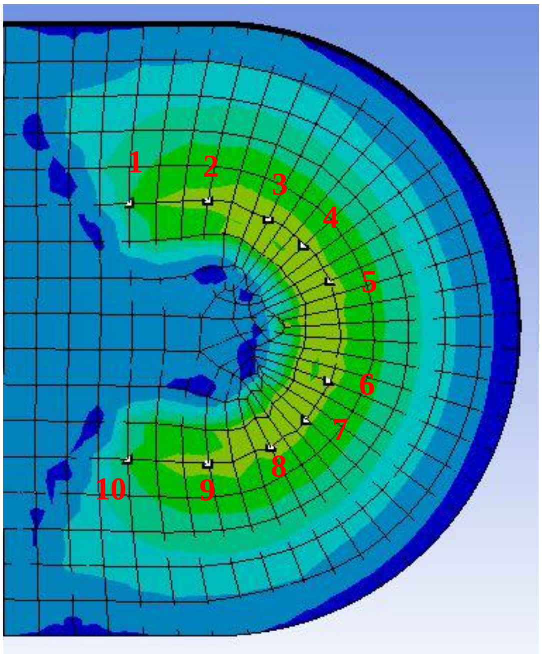


Figure 3.6: Number of nodes selected on the tibia

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The purpose of this chapter is to describe the result of kicking experiment that used to find the parameter for the simulation process. There are 2 kicking that involve in the experiment which is Inside Kicking and also Instep Kicking. This chapter also will describe the result of the simulation of the knee joint with certain condition of meniscus which is healthy meniscus and torn meniscus. Other than that, the shape of the meniscus is being investigated by comparing with the not normal shape.

4.2 INSIDE AND INSTEP KICKING

4.2.1 Experimental Result

Inside and instep kicking is two of many types of kicking that always be used in the soccer competition. The kicking experiment has been conducted by using subjects that is come from Majlis Sukan Negeri Terengganu (MSNT). The purpose of the experiment is to observe the behavior in term of biomechanics of the kicking leg and also the effect on the ball when being kicked. For this paper, the result used is just the velocity of the ball after impact with the foot. In this chapter, there will be comparison between the two types of kicking to show which one will result with the better performance and output force transmitted towards the ball.

Table 4.1: The ball velocity after impact for Inside Kicking

Type of Kicking	**Inside Kicking**								
Subject		1			2			3	
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	15.54	14.19	15.12	16.95	18.35	16.89	19.09	19.53	21.11
Average (m/s)		14.95			17.40			19.91	

Table 4.2: The ball velocity after impact for Instep Kicking

Type of Kicking	**Instep Kicking**								
Subject		1			2			3	
No. of Trial	1	2	3	1	2	3	1	2	3
Ball Velocity (m/s)	16.27	18.54	16.50	20.97	20.06	16.69	24.89	24.23	25.27
Average (m/s)		17.10			19.24			24.80	

Table 4.1 and 4.2 show the results of experiment between the two types of kicking which are Inside and Instep. Three subjects are used to do the kicking where 3 trials are needed in order to find the average value. From the tabulated result, a graph is plotted by comparing the two types of kicking in as shown Figure 4.1.

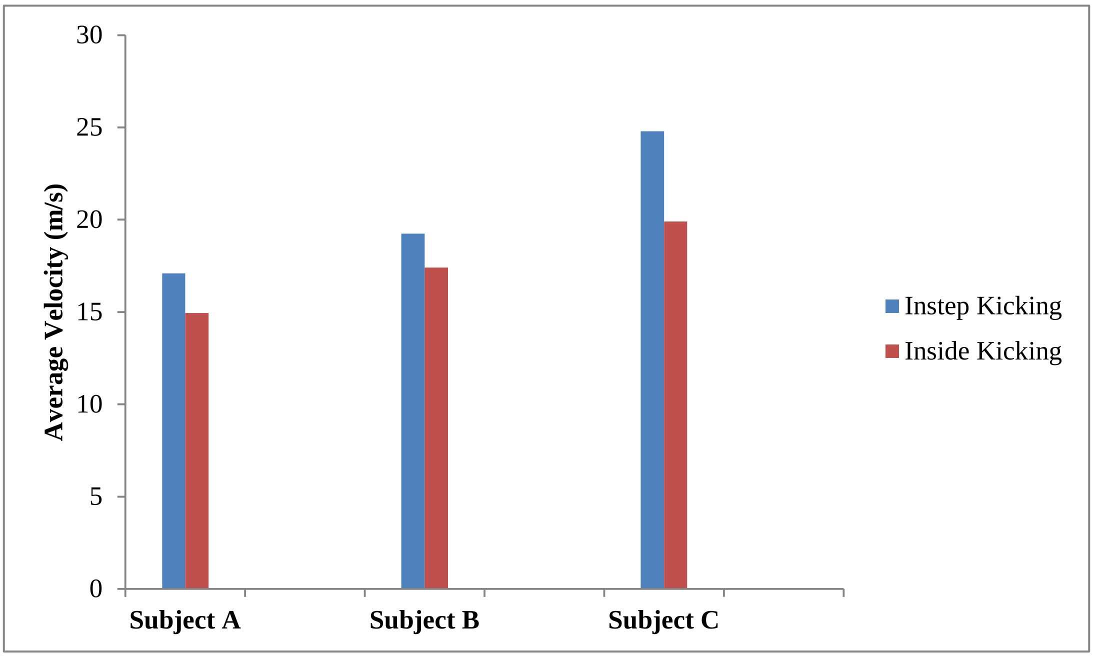


Figure 4.1: Average ball velocity after impact

Figure 4.1 shows the comparison between the two types of kicking is plotted in one graph. It is clearly shown that, for each subject, their instep kicking is the highest in velocity after the impact with the foot. It is clarified with the application for each of the kicking. Inside kicking which result with low average ball velocity after the impact is normally used for short pass in the soccer game compared with the instep kicking which is always be used for the high speed ball like free kick or shooting. For the simulation process, force parameter is needed. The force is calculated from the average ball velocity after the impact and got the impact force. Then, the force is being distributed by using some angles related to those two kicking that have been mentioned in Chapter 3. The difference between the two kicking is just the value of force, since instep kicking result with highest force, the result simulation will be focus on the highest force only.

4.2.2 Calculation for Inside Kicking

Table 4.3: Average ball velocity for Inside Kicking

Type of Kicking	**Inside Kicking**		
Subject	1	2	3
Average Ball Velocity (m/s)	14.95	17.40	19.91

Ball Velocity: 19.91 ms^{-1}

$$\text{Acceleration, a} = \frac{\text{velocity}}{\text{time}} = \frac{\text{v}}{\text{t}}$$

$$\text{a} = \frac{19.91\ \text{ms}^{-1} - 0}{0.01\ \text{s}}$$

$$\text{a} = 1991\ \text{ms}^{-2}$$

$$\text{Force, F} = \text{ mass } \times \text{acceleration} = \text{ma}$$

$$\text{F} = (0.43\ \text{kg})(1991\ \text{ms}^{-2})$$

$$\text{F} = 856.13\ \text{N}$$

In order to get the value of force that act towards the ball at the time of impact, certain angle will be considered in the calculation as shown in Figure 3.3.

$$\text{F} = (\ 856.13\ \text{N}\ ) \cos 10 = 843.12\ \text{N}$$

$$\text{F} = (\ 843.12\ \text{N}\ ) \cos 75 = 218.21\ \text{N}$$

$$\text{F} = 218\ \text{N}$$

From the final value of F above, it is shows that 218 N will be experienced by the ball and also by the foot based from the Newton's third law of motion that state about every force is balanced by an equal but opposite force.

4.2.3 Calculation for Instep Kicking

Table 4.4: Average ball velocity for Instep Kicking

Type of Kicking	**Instep Kicking**		
Subject	1	2	3
Average Ball Velocity (m/s)	17.10	19.24	24.80

Ball Velocity: 24.80 ms^{-1}

$$\text{Acceleration, a} = \frac{\text{velocity}}{\text{time}} = \frac{\text{v}}{\text{t}}$$

$$\text{a} = \frac{24.80\ \text{ms}^{-1} - 0}{0.01\ \text{s}}$$

$$\text{a} = 2480\ \text{ms}^{-2}$$

$$\text{Force, F} = \text{mass} \times \text{acceleration} = \text{ma}$$

$$\text{F} = (0.43\ \text{kg})(2480\ \text{ms}^{-2})$$

$$\text{F} = 1066.4\ \text{N}$$

In order to get the value of force that act towards the ball at the time of impact, certain angle will be considered in the calculation as shown in Figure 3.4.

$$\text{F} = (\ 1066.4\ \text{N}\ ) \cos 10\ = 1050.2\ \text{N}$$

$$\text{F} = (\ 1050.2\ \text{N}\ ) \cos 60\ = 525.1\ \text{N}$$

$$\text{F} = (\ 525.1\ \text{N}\ ) \cos 45\ = 371.3\ \text{N}$$

$$\text{F} = 371\ \text{N}$$

From the final value of F above, it is shows that 371 N will be experienced by the ball and also by the foot based from the Newton's third law of motion that state about every force is balanced by an equal but opposite force.

Table 4.5: Impact Force and Force Distributed for Inside Kicking

Type of Kicking	**Inside Kicking**		
Subject	1	2	3
Force (N)	643	748	856
Force Distributed (N)	164	191	218

Table 4.6: Impact Force and Force Distributed for Instep Kicking

Type of Kicking	**Instep Kicking**		
Subject	1	2	3
Force (N)	735.30	827.30	1066.40
Force Distributed (N)	256	288	371

From the Table 4.5 and 4.6, it is clearly stated that instep kicking result with highest impact force and force distributed. The maximum force distributed which is 371 N will be used as the force parameter in the simulation process in order to observe the reaction that act towards the tibia when the force is applied through the knee joint.

4.3 VALIDATION

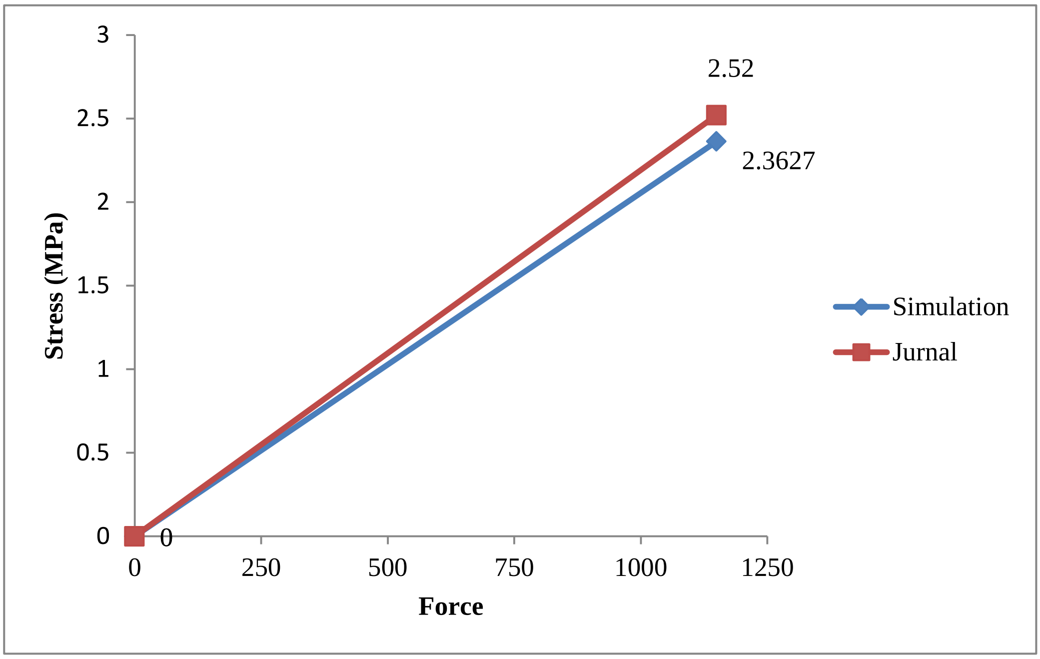


Figure 4.2: Comparison value of stress in the simulation with the previous study

Figure 4.2 show the comparison of the simulation result between the journal by E. Pena et al. (2005) entitled 'Finite Element Analysis of the effect of Meniscal Tears and Meniscectomies on Human Knee Biomechanics'. The stress value that being compared is the stress result read on the surface of the tibia. From the journal, the parameter used in the simulation is used for the validation purpose. The force used is about 1150 N that applied on the upper surface of the femur. The result is taken on the tibia after there is compression between the femur, meniscus and the tibia. From the result as shown on the graph, the error that differentiates between the simulation result and journal result is about 6.24%. The error is in the range of validation purpose since the range for Finite Element Analysis is 5% to 9%.

4.4 KNEE JOINT STRESS ANALYSIS

4.4.1 Knee Joint with Healthy Meniscus

The simulations of the knee joint are using 3 designs consisting of femur, meniscus and tibia. The design of the meniscus used is in healthy state means that there is no tear on the surface of the meniscus. The complete design consist of 3 parts is given with a calculated distributed force. The force used is the highest force calculated which is 371N. The bottom part of the tibia is chose as the part that first received the distributed force after the impact between the foot and the ball. The result is observed once the force acted through the tibia, whether the meniscus doing its job as the load transmission between the joint or not.

4.4.2 Knee Joint with Torn Meniscus

The simulations of the knee joint are using the same 3 designs consisting femur, meniscus and tibia. The type of torn meniscus used will differentiate between the knee joint with healthy meniscus and knee joint with torn meniscus. There are 3 type of torn meniscus used in the simulation which are longitudinal tear, horizontal tear and radial tear. Each of the type has its own specific tear. For longitudinal, bucket handle tear is used. For horizontal tear, flap tear is used. Last but not least, for radial tear, parrot beak tear is used. The simulation step is just the same where distributed force will act through the bottom part of the tibia and the expected result will be seen on the surface of the tibia directly under the meniscus.

4.5 KNEE JOINT WITH HEALTHY MENISCUS

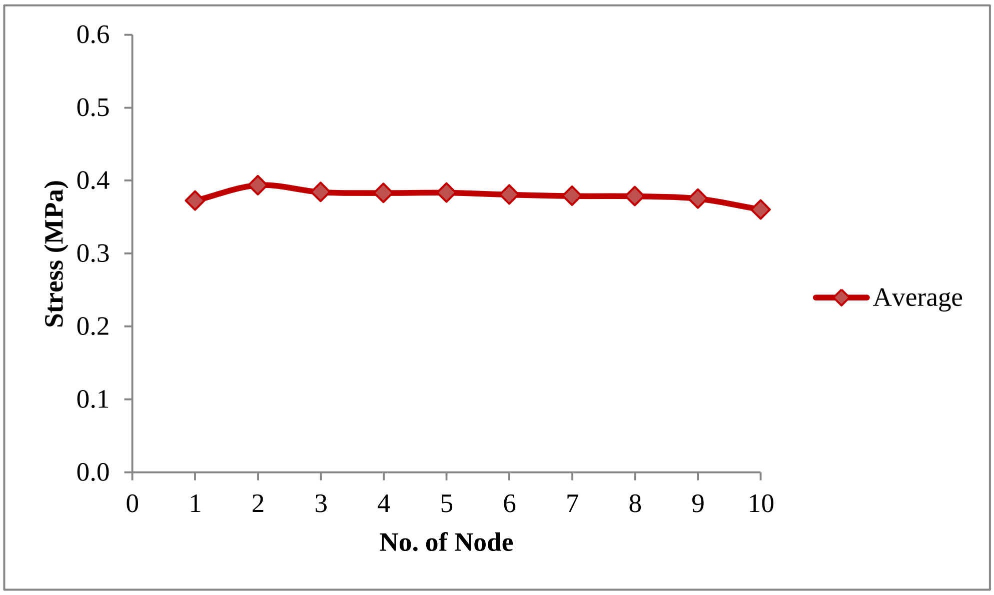


Figure 4.3: Stress distribution and the number of node on the tibia for Healthy Meniscus

By referring to Figure C-1, C-2 and C-3 in Appendix C, it is the result of the simulation of knee joint which having healthy meniscus. Stress result from 3 designs is taken and the average value is calculated in order for graph plotting. The stress result for each design is tabulated in the Table B-2 as shown in Appendix B. From the result of node stress, it is clearly stated that the value is in the same range and nearly the same. This is because the load is transmitted within the joint direct to the meniscus with healthy and perfectly body without tears. Healthy meniscus has doing its job as the load transmission within the knee joint. By transmitting the load, meniscus has successfully preventing an excessive stress from happens within the joint. Excessive stress within the knee joint is one of the most painful pains someone has to bear by their leg. This is all because of the meniscus is not well functioning transmitting the load. The result shown in Figure 4.3 will be used for the comparison between the knee joint with healthy meniscus and the knee joint with torn meniscus. By reviewing the comparison between the two cases, an observation can be made to see the functionality of the meniscus is affected or not if there is a damage on the meniscus body.

4.6 KNEE JOINT WITH BUCKET HANDLE TEARS

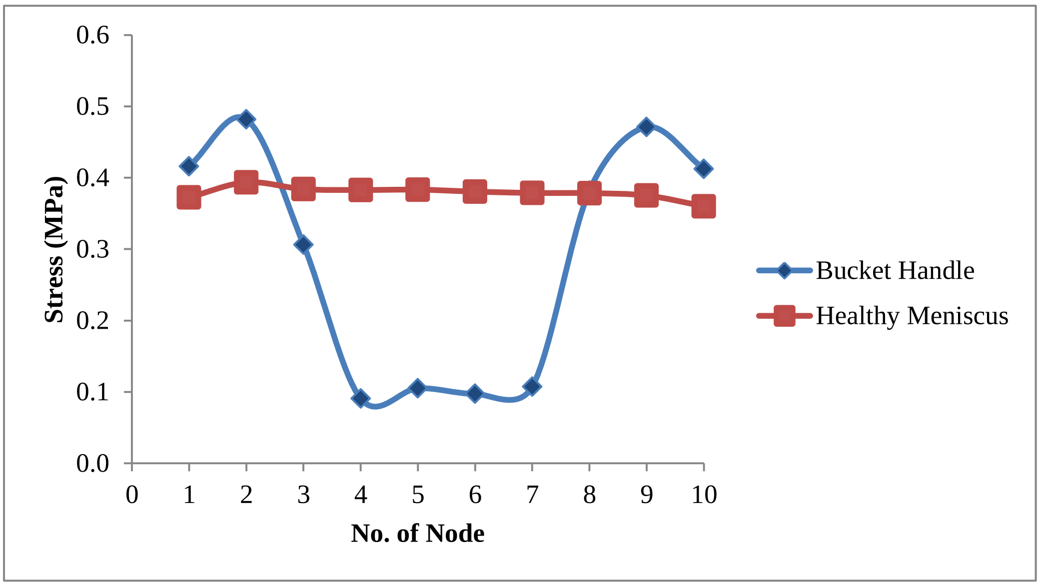


Figure 4.4: Stress distribution and the number of node on the tibia for Bucket Handle meniscus

By referring Figure C-4, C-5 and C-6 in Appendix C, it is the result of simulation of knee joint which having longitudinal meniscal tears which is bucket handle type. The result shows the different value of stress distribution on the tibia that is located under the meniscus. The stress result for each design is tabulated in the Table B-3 which can be referred in Appendix B.

From the case of knee joint which having longitudinal meniscal tears which is bucket handle type, the torn on the meniscus is the worst among the other types. Early conclusion can be made where the function of meniscus is still there but not fully functional as the load distributor between the femur and the tibia. As the result shown on the Figure 4.4, it is clearly different in value comparing between the two cases. For the case with healthy meniscus, the stress distribution on the tibia is well distributed and in the same range of stress. By comparing with the other case which is knee joint with bucket handle meniscus, the result of stress for each node is much different. From this, the stress is not well distributed on the tibia when the knee joint is being loaded.

From the graph pattern as shown in Figure 4.4, there is slightly increase and decrease for the value of stress on each node. For torn meniscus case, node 1 and 10 which are the starting and ending node is about the same in value. The highest stress is shown on the node 2 and 9. After node 2 until node 4, the stress acted on the tibia is decrease different with node 7 until 9 which shows the increase value in stress. From the node 4 until node 7, the minimum stress value is recorded. From all the description regarding the node stress, it is clearly shown the stress is not evenly distributed compare with the case with healthy meniscus.

An early observation can be made based on the description above. From the design of the 'Bucket Handle' meniscus, the torn is located around the center of the meniscus body. This means that the selected nodes on the tibia from node 4 until 7 are located directly under the meniscus tear. The stress result shows that minimum stress is recorded between these nodes. That is mean that the minimum value of stress will result on the surface of the tibia that located directly under the meniscus tear. When the force is applied, a net force will be transmitted through the meniscus body, a higher value of stress is recorded on node 1, 2, 9 and 10 where these nodes are being loaded under the meniscus body that is no damage.

4.7 KNEE JOINT WITH FLAP TEAR MENISCUS

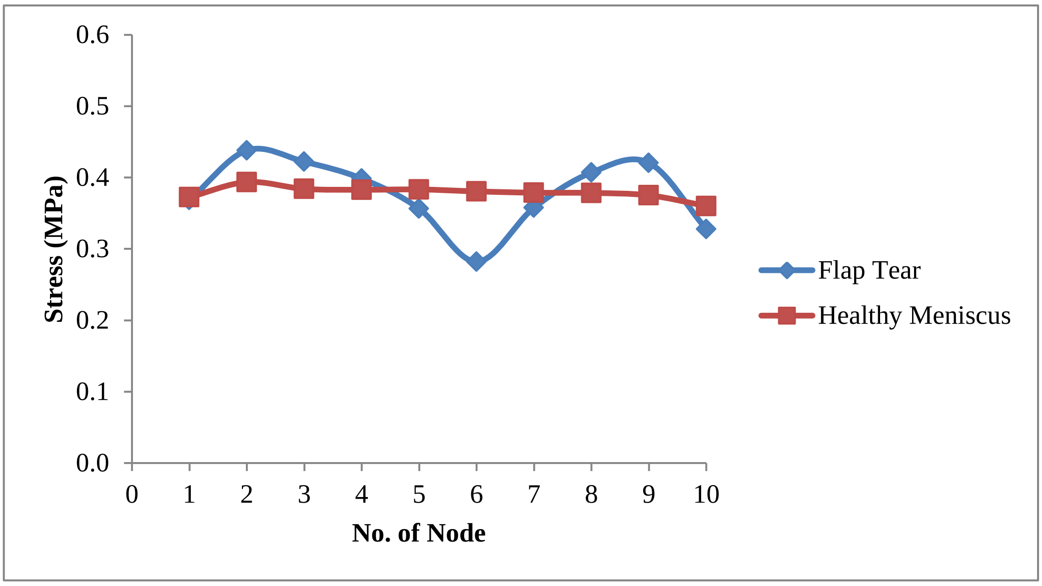


Figure 4.5: Stress distribution and the number of node on the tibia for Flap Tear meniscus

By referring to the Figure C-7, C-8 and C-9 in Appendix C, it is the result of the simulation of knee joint which having horizontal tears which is flap tear type. The result shows the different value of stress distribution alongside of the tibia that is located under the meniscus. The result of stress for each design is tabulated in the Table B-4 in Appendix B. The average value of stress for the 3 design is calculated.

From the case of knee joint with horizontal tears which is flap type, the torn is not worst as bucket handle type. The torn still can affect the meniscus to lose its main function which is load transmission between the joint. From the figure for each design, the stress distribution alongside the tibia can be seen. This can be proved by reviewing the Figure 4.5 which shows the pattern of the stress distribution and also the comparison with the knee joint with healthy meniscus. From the comparison, it is shown that knee joint with healthy meniscus is behave in a well-mannered in term of its stress distribution. This is because the meniscus is still fully functioning as the load transmission between the joint.

The result of the graph shows increasing and decreasing stress that behaves by the nodes. Compare with the graph pattern result from the bucket handle tear, flap tear is having less effect in term of its stress distribution on the tibia. From the result of knee joint with bucket handle tear, it is clearly shows that there is sudden increase and decrease stress behave by some nodes The pattern of the graph shows that, node 2 and node 9 is having the highest stress compared with others. Starting from node 3 until node 6, sudden decrease is recorded. After that, from node 6, there is sudden increase in stress until node 9 which is one of the highest stresses recorded.

From the observation, the part that there is minimum value of stress is located directly under the torn meniscus while highest stress recorded on the tibia that is located under the end side of the meniscus. From the design of the 'Flap Tear' meniscus, it is clearly shows that tear also located around the center of the meniscus body but not too much compared with bucket handle meniscus. From the graph, node 6 on the tibia is having minimum value of stress where it is located directly under the meniscal tears. Same theory like before, if there is damage on the meniscus body, a net force will not be transmitted on that part. The net force will be transmitted around the non-damage body of meniscus when the force is applied.

4.8 KNEE JOINT WITH PARROT BEAK MENISCUS

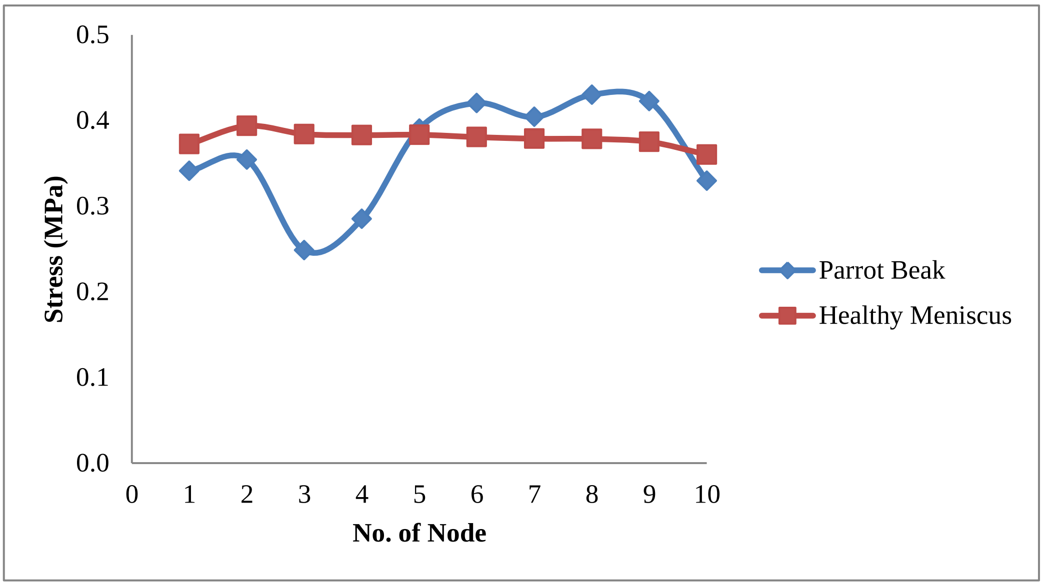


Figure 4.6: Stress distribution and the number of node on the tibia for Parrot Beak meniscus

By referring to the Figure C-10, C-11 and C-12 in Appendix C, that is the result of the simulation of the knee joint which having radial tear on the meniscus which parrot beak tear. The result shows the different value of stress distribution alongside of the tibia that is located under the meniscus. The result for each design then will be tabulated in the Table B-5 in Appendix B. By having the result for each design, the average value for each node is calculated.

From the case of knee joint which having radial tear which is parrot beak tear, the tear is also not worst as the bucket handle tear. The tear is kind of flap tear just having different of tear displacement. Although the tear is not worst as the bucket handle but it still can give an effect towards the meniscus function which is the load transmission. As shown in the result of the simulation in Appendix C, the load is still be transmitted alongside of the tibia but not in well mannered. Unlike the knee joint with healthy meniscus, the meniscus is fully functioning by transmitting the load evenly and well-mannered on the tibia directly under the meniscus. This can be proved by observing the result of the Figure 4.6 which is the graph of Stress vs. Number of Node.

The Figure 4.6 shows the pattern of stress distribution on the tibia of the knee joint when it is being loaded and also the comparison of stress distributed between the knee joint with parrot beak and the knee joint with healthy meniscus. The result of the graph shows some node that having increasing and decreasing of stress from its state where knee joint is having healthy meniscus. The range of stress is also about the same for these two cases. From what can be describes from the Figure 4.6, there is no sudden decrease of stress for each node. There is just slightly decrease in stress from node 2 until node 3 and then increasing until node 6.

From the design of ‘Parrot Beak’ meniscus, it is clearly shows that the tear on the meniscus body is located around the center of the meniscus body. As shown on Figure 4.6 above, node 3 shows the minimum value of stress on the surface of the tibia. This is also the result where node 3 is located directly under the meniscus tear. So, there is no net force being transmitted on that part. Since the other part is perfectly in shape without any damage, the net force is being transmitted perfectly. That is why the stress value that result on the other node is high.

4.9 EQUATION FOR GRAPH OF AVERAGE

4.91 Knee Joint with Bucket Handle Meniscus.

Figure 4.7 shows the graph of stress pattern that act on the tibia under the meniscus when the knee joint is being loaded. From the raw data of average stress tabulated in the Table B-3 as shown in appendix, smooth graph pattern is constructed. From the graph pattern, one equation is generated in order to represent the pattern of the stress distributed on the surface of the tibia after load is applied.

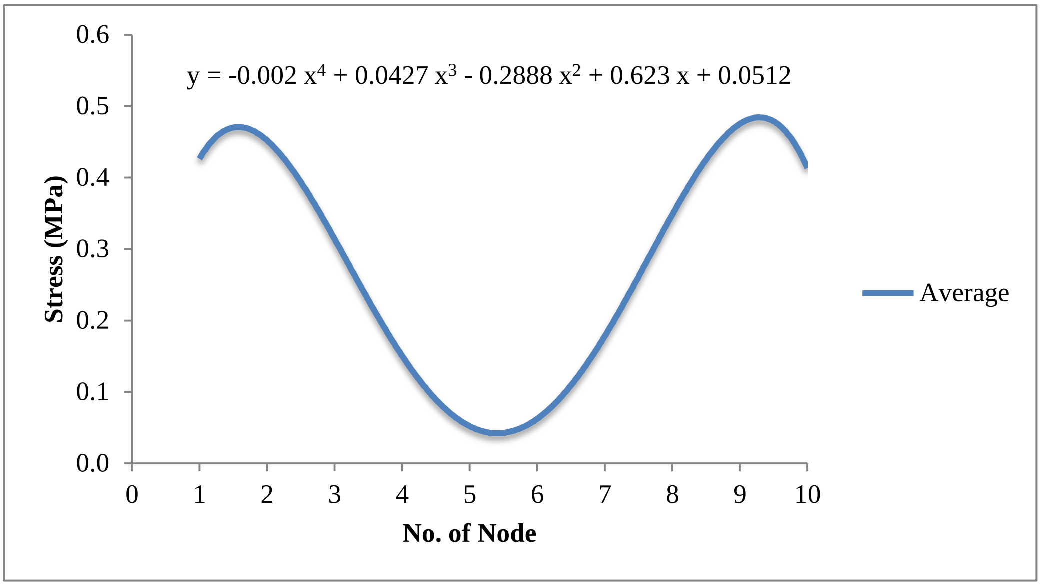


Figure 4.7: Pattern and equation for stress distribution acted on tibia for Bucket Handle meniscus

Graph equation:

$$y = -0.002\,x^4 + 0.0427\,x^3 - 0.2888\,x^2 + 0.623\,x + 0.0512$$

Where, x = Stress

y = No. of Node

Simulation result, when $x = 1\,, y = 0.41613$

Comparing with the equation generated from the graph:

$$y = -0.002(1^4) + 0.0427(1^3) - 0.2888(1^2) + 0.623(1) + 0.0512$$

$$y = 0.4261$$

Percent error between the simulation result and the calculated result:

$$\left(\frac{\text{calculated} - \text{simulation}}{\text{calculated}}\right).100\%$$

$$\left(\frac{0.4261 - 0.41613}{0.4261}\right).100\% = 2.34\ \%$$

From the value above which is 2.34% of error between the calculated and simulation value, the value seem to be small. This shows that the equation that comes out to present the pattern of stress distribution of knee joint with bucket handle meniscus can be used.

4.9.2 Knee Joint with Flap Tear Meniscus.

Figure 4.8 shows the graph of stress pattern that act alongside of the tibia under the meniscus when the knee joint is being loaded. From the raw data of average stress tabulated in the Table B-4 as shown in appendix, smooth graph pattern is constructed. From the graph pattern, one equation is generated in order to represent the pattern of the stress distributed on the surface of the tibia after load is applied.

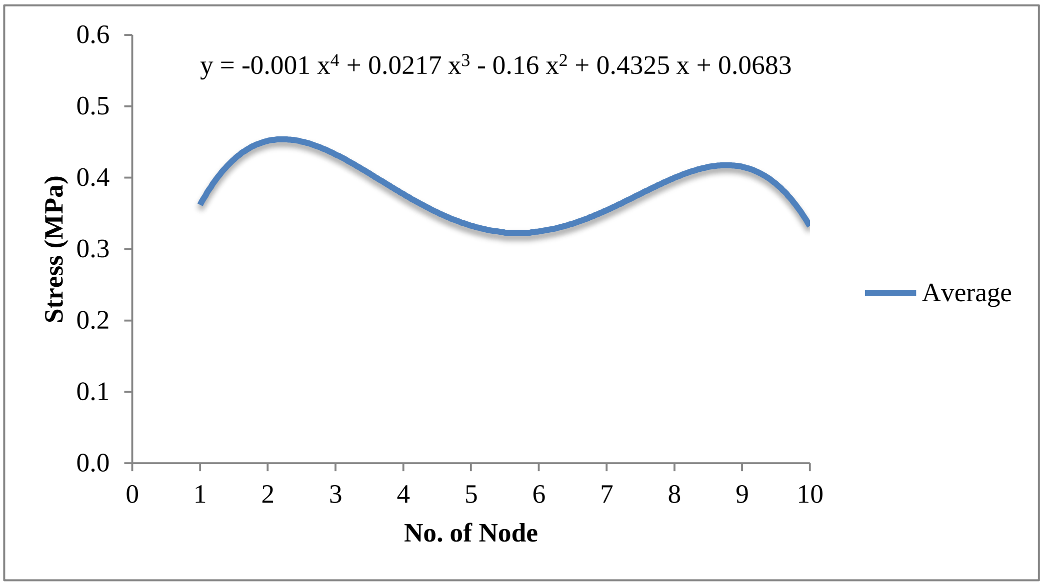


Figure 4.8: Pattern and equation for stress distribution acted on tibia Flap Tear meniscus

Graph equation:

$$y = -0.001\,x^4 + 0.021\,x^3 - 0.16\,x^2 + 0.4325\,x + 0.0683$$

Where, x = Stress

y = No. of Node

Simulation result, when $x = 1$, $y = 0.36837$

Comparing with the equation generated from the graph:

$$y = -0.001\ (1^4) + 0.021\ (1^3) - 0.16\ (1^2) + 0.4325\ (1) + 0.0683$$

$$y = 0.3608$$

Percent error between the simulation result and the calculated result:

$$\left(\frac{\text{calculated} - \text{simulation}}{\text{calculated}}\right) .100\%$$

$$\left(\frac{0.3608 - 0.36837}{0.3608}\right) .100\% = 2.1\ \%$$

From the value above which is 2.1% of error between the calculated and simulation value, the value seem to be small. This shows that the equation that comes out to present the pattern of stress distribution of knee joint with flap tear meniscus can be used.

4.9.3 Knee Joint with Parrot Beak Meniscus.

Figure 4.9 shows the graph of stress pattern that act alongside of the tibia under the meniscus when the knee joint is being loaded. From the raw data of average stress tabulated in the Table B-5 as shown in appendix, smooth graph pattern is constructed. From the graph pattern, one equation is generated in order to represent the pattern of the stress distributed on the surface of the tibia after load is applied.

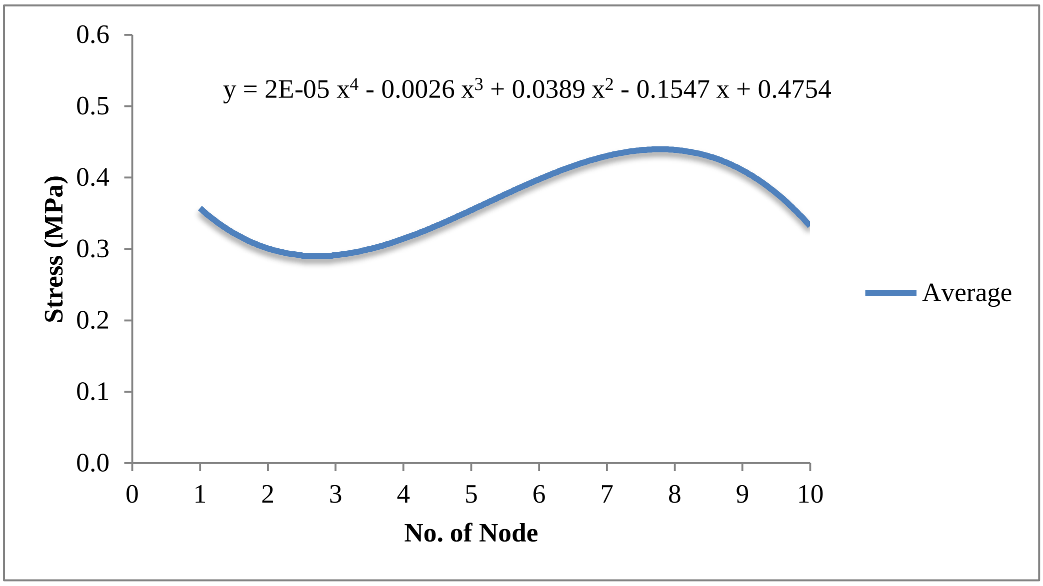


Figure 4.9: Pattern and equation for stress distribution acted on tibia for Parrot Beak meniscus

Graph equation:

$$y = 0.00002\,x^4 - 0.0026\,x^3 + 0.0389\,x^2 - 0.1547\,x + 0.4754$$

Where, x = Stress

y = No. of Node

Simulation result, when $x = 1\,,\;\; y = 0.34103$

Comparing with the equation generated from the graph:

$$y = 0.00002\,(1^4) - 0.0026\,(1^3) + 0.0389\,(1^2) - 0.1547\,(1) + 0.4754$$

$$y = 0.35702$$

Percent error between the simulation result and the calculated result:

$$\left(\frac{\text{calculated} - \text{simulation}}{\text{calculated}}\right).100\% = \text{Percent error}, \%$$

$$\left(\frac{0.35702 - 0.34103}{0.35702}\right).100\% \ = 4.48\ \%$$

From the value above which is 4.48% of error between the calculated and simulation value, the value seem to be small. This shows that the equation that comes out to present the pattern of stress distribution of knee joint with parrot beak meniscus can be used.

4.10 DEFORMATION ANALYSIS

4.10.1 Simulation on Wedges and Non-Wedges Meniscus

A simulation that focuses on the meniscus is carried out in order to find out the importance of wedges shape of meniscus. By designing one meniscus with not normal shape and doing simulation on it, a comparison between the wedges meniscus and non-wedges meniscus can be carried out. The data of the simulation is tabulated in the Table B-6 as shown in Appendix B.

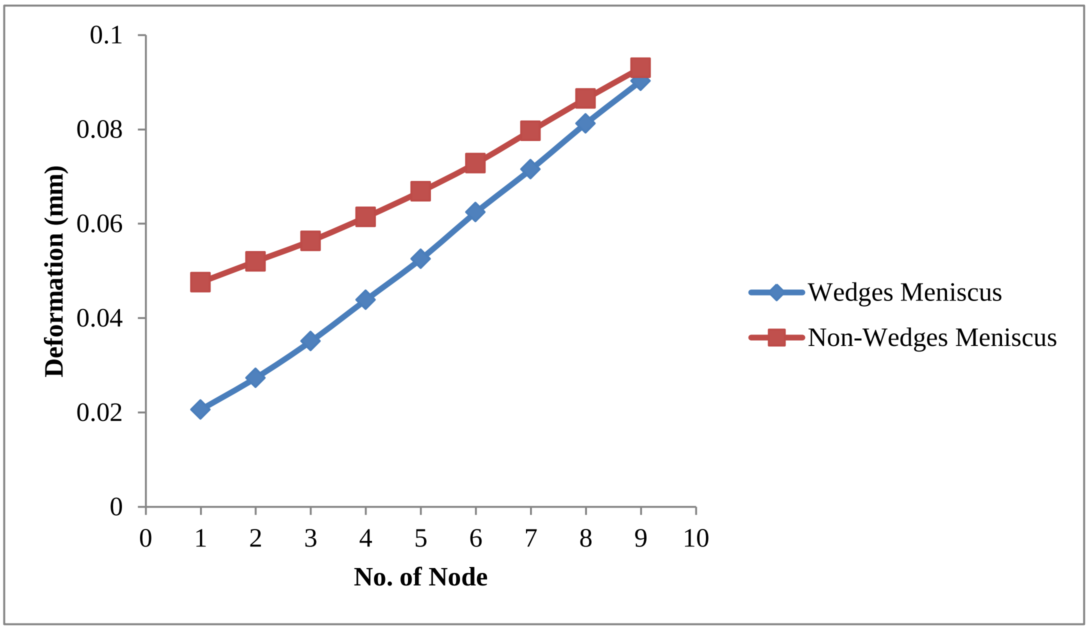
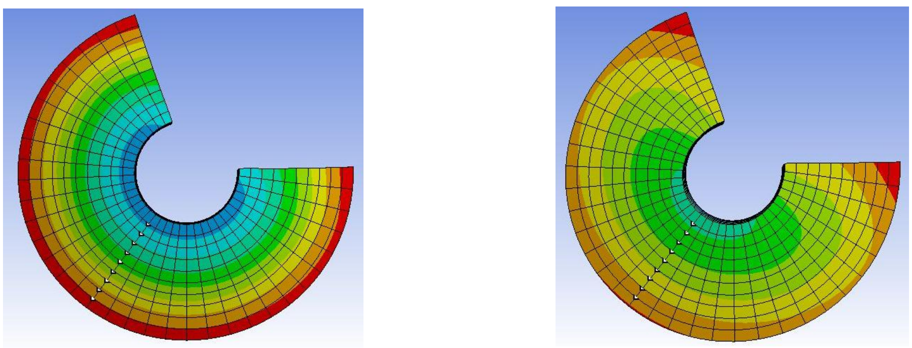


Figure 4.10: Comparison between the Wedges and Non-wedges Shape of Meniscus

The importance of wedges shape for meniscus is after being loaded, the meniscus will extrude from its original shape and creates more congruent surfaces between the femur and tibia. Therefore, the transmitted and distributed load that across the upper or lower bone will over the large surface area. As shown in the Figure 4.10 above, for wedges meniscus, it is started to deform constantly from least to many displacement. This can prove that wedges meniscus is started to extrude continuously. By having this kind of characteristic, a large surface area of tibia will be covered by the meniscus when load is applied.

Compare with the non-wedges meniscus, after 371N of distributed force is applied through the tibia it is clearly shown that the deformation of non-wedges meniscus is different and not uniform. This can be seen from the result shown on the graph where the deformation of the non-wedges meniscus started differently with the wedges meniscus. This mean that the non-wedges meniscus is less extrude when the load is applied. So that, the contact area of the tibia that being covered by the meniscus is less. This can result with the stress acted on the tibia after being loaded is greater compare with the wedges meniscus which can cover so much contact area of the tibia. The result of the simulation can be seen by the Figure 4.11. Figure 4.11.a is the wedges meniscus while Figure 4.11.b is the non-wedges meniscus.



a) b)

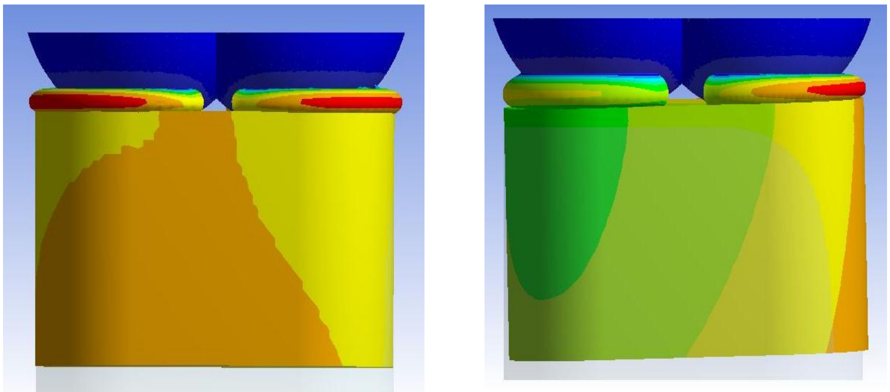
Figure 4.11: Result of meniscus simulation a) Wedges meniscus b) Non-Wedges meniscus

4.11 KNEE STABILIZER

4.11.1 Simulation of Meniscus as Knee Stabilizer

The main purpose of the meniscus is to transmit the load within the knee joint which can help to prevent an excessive stress that act towards the joint. The healthiness of the meniscus without any tear or damage is important for the joint. The healthy meniscus can fully functioning towards the joint which can transmit the load across the knee in well-mannered. This is also the result with the knee that is more stable when the load is applied. By having healthy meniscus, the knee joint design is well compressed.

Different with the knee joint that has torn meniscus which the meniscus is not well functioning that can cause the load is not well transmit through the tibia. The simulation result shows that the knee joint with torn meniscus is not well compressed and the compression is more on the side where there is torn meniscus. Although the tear is small, meniscus is still loss its ability to maintain the stability of the knee joint. This shows that how important is the meniscus towards the knee joint in order to protect it. Figure 4.12 shows the simulation result comparing between the knee joint with healthy and torn meniscus.



a) b)

Figure 4.12: Simulation of Knee Joint a) Healthy Meniscus b) Torn Meniscus

4.12 THE MENISCUS AS LOAD TRANSMISSION

The main function of the meniscus of knee joint is to act as the load transmission between the joint of femur and the tibia. From the simulation process, meniscus that is located between the femur and tibia is being compressed after an external force is applied through the bottom part of the tibia. From its physical characteristic which is elastic, meniscus is one element that is suitable to act as the absorber of the knee joint. Since it is from the elastic material, anything like weight bearing or force that act towards the knee, meniscus will do its job by absorbing it and give some comfort ability towards the joint without excessive stress. The compressive ability that meniscus have is also act like the cushions which is supporting the load by compressing and spreading the weight evenly within the knee joint as can be seen in Figure 4.13. The common description of the menisci is that they are semi-lunar fibrocartilagenous disks, whose main function is to increase the congruency of the tibiofemoral joint, thereby decreasing the stress in the joint through an increase in the contact area. (McDermott *et al.*, 2008). Any movement that results from femur and tibia, meniscus will also react the same way. By this, the congruency of knee joint still can be maintained and the joint will not face any excessive stress that can result with pain if the meniscus is not functioning well.

This can be proved by reviewing the result of the simulation of the knee joint with healthy meniscus. Result of the simulation can be seen in Figure C-1, C-2 and C-3 as shown in Appendix C. Healthy meniscus is playing an important role towards the knee joint. Its ability to maintain the knee joint from having excessive stress by transmitting the stress evenly and well-mannered is a proved that the role of the meniscus is as the load transmission. Since the meniscus is a compressive material, force that react towards the joint will be experienced and transferred across the meniscus body. This phenomenon is a common thing called as ‘hoop stresses’. The compression force across the knee, as it is transmitted from the femur through the meniscus to the tibia, causes tension along the circumferential collagen fibres within the meniscal tissues. (McDermott *et al.*, 2008). This hoop stress phenomenon is the reason why the knee joint can maintain its congruency without any failure. McDermott *et al.*, (2008) has stated in his literature regarding the hoop stress within the meniscus body, it is a result from a net resultant force that generated when load is applied.

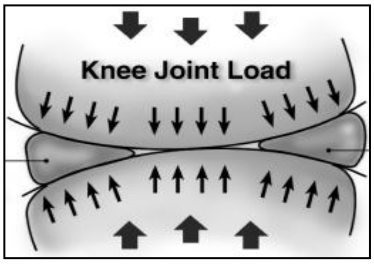


Figure 4.13: Healthy meniscus distributed the load evenly across the knee joint

It is in different case if the knee joint is having with torn meniscus. There are many types of tears that can attack the meniscus. In this paper, there are 3 types of tears that used in the simulation process which are bucket handle, flap and parrot beak tears as can be seen in the Figure 4.14. Meniscus tends to get injured during movements that forcefully twist your knee while bearing weight. This is always happen for the young people who are actively in sport. The meniscus also tends to grow weaker with age, and tear as a result of minor injuries or movements. (Knee and Meniscus, 2013). By reviewing the 3 result of simulation, it is clearly shown that the stress that is transmitted by the meniscus to the tibia surface is not well-mannered and not evenly in value. This is the result of torn meniscus that tends to lose its main function towards the knee joint. When your meniscus is damaged and or torn, it starts to move abnormally inside the joint, which can cause it to become caught between the bones of the joint. (Knee and Meniscus, 2013). That is the reason why the torn meniscus is losing its load transmission role. When torn is exist on the surface of the meniscus, the movement of the meniscus will also be affected. When load is applied, the compressive ability that brings a net force cannot be well transmitted across the tibia. Hoop stress phenomenon that exists inside the meniscus will be disturbed and lose the ability to give a full congruent towards the knee joint. Once the movement of the meniscus is affected, the contact area of the meniscus after it is being compressed across the tibia will also get an effect.

As shown in Table 3.5, it is clearly shown that bucket handle tear has the tear that is the worst compare with the other tears. From the tear that can be seen, there is a hole on the meniscus surface. Hence, the surface of compressive meniscus will decrease in area. The simulation result for knee joint with bucket handle tears shows sudden change with the value of stress for certain nodes. This is the result that comes from the shape of tear itself. When the meniscus is being loaded, there is no net force that being transmitted to the meniscus body that is damage. The load transmitted will directly towards the body of meniscus only. That is why, in the simulation result, there are some nodes that having a minimum value and some nodes that have maximum value. Referring to the other type of tears which are flap and parrot beak, the tear part is just small at the tip of the meniscus. The size of tear part whether it is small or large did not give an excuse to not affect the role of meniscus as the load transmission. As shown in Figures 4.5 and 4.6, the difference between those 2 graphs and the graph of bucket handle case is so much difference. For flap and parrot beak case, the stress that distributed alongside of the tibia surface is nearly in the same range.

4.13 SIMULATION OF FULL LEG WITH AND WITHOUT KNEE PAD

A simulation of full leg with and without knee pad is carried out in order to observe what will be the reaction or effect on the meniscus after an external force is acted through the leg. Simulation result shows that the external force around 1000N that reacts through the leg can goes through the internal part of the knee. Hence, this also gives an effect towards the meniscus that located between the femur and the tibia. Simulation result for full leg with and without knee pad can be reviewed on Figure C-13 and C-14 as shown in Appendix C.

For observing the effect on the meniscus body after the external force is applied, a result is focus on the meniscus itself. For the two cases which are full leg with and without knee pad, meniscus is reacting differently. When an external force is given on the surface of the design, there is bending on the knee joint which affected the meniscus body. That effect result with the deformation of meniscus where the meniscus is being extruded and compressed. By differentiate the two cases of leg with and without knee pad, the bending of knee joint result more on the leg without knee joint. Figures 4.14 and 4.15 show the simulation result that focus on the meniscus body after it is being compressed

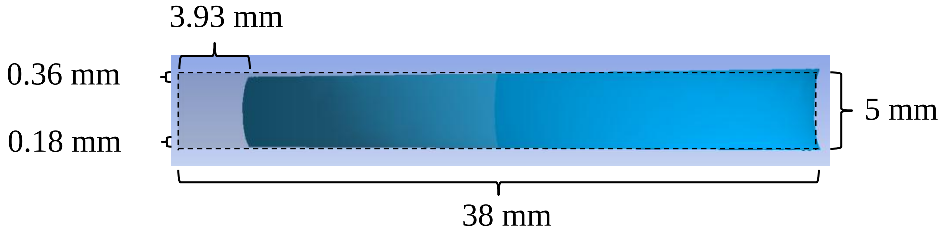


Figure 4.14: Side view of meniscus body after being compressed for leg without knee pad

Figure 4.14 shows the side views of the meniscus body before and after the compression happen. When the external force is applied, the force can goes through the knee joint pass the skin layer. Since there is no knee pad as an absorber, the effect that went through the knee joint is much greater and give out a large number of deformation acted by the meniscus body. As the external force result with the knee joint bending, meniscus body is being compressed. As shown on the Figure 4.14, meniscus body being compressed towards the front side of the body. From the initial thickness of the meniscus body which is 5 mm, a deformation take place on the front side since the knee joint is bend result from an external force. As shown on the figure, around 3.93 mm of bending happen towards the joint. A comparison can be made between the leg with and without knee pad in order to observe the effectiveness of the knee pad as shock absorber during the impact.

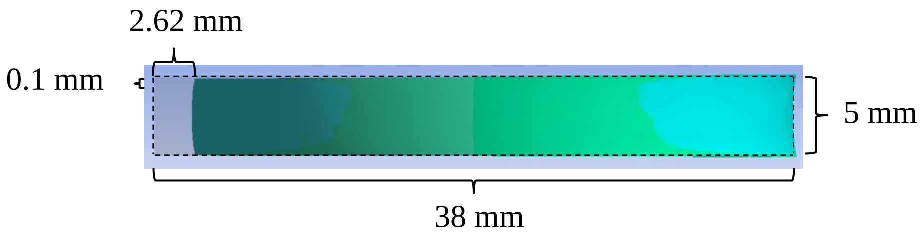


Figure 4.15: Side view of meniscus body after being compressed for leg with knee pad

Figure 4.15 shows the side views of the meniscus body before and after the compression happen. As the force is goes through the skin towards the internal part, knee joint has bend as the result of the force exerted. This causes the meniscus to deform as the result of the meniscus compression. Since there is knee pad that attached to the leg as an absorber, the effect that went through the knee joint is lower compared to the leg without knee pad. The deformation that takes place towards the meniscus body also is less. This shows that the knee pad prove its functionality towards the knee joint. Although the effect compared to the leg without knee pad is less, but still give out with different value of result.

As shown on the Figure 4.15, meniscus body is also being compressed towards the front side of meniscus body. Comparing with leg without knee pad, the compression that take place for leg with knee pad is less. For with knee pad, meniscus being compressed around 0.1 mm while for the leg without knee pad, the meniscus body being compressed around 0.36 mm. The bending of knee joint also gives out with different result. Less bending result for leg with knee pad which is 2.62 mm while 3.93 mm is the bending for the knee joint for leg without knee pad. This shows how effective the knee pad is towards the knee.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

In this chapter, a conclusion is made which summarize the whole part of this study and also included the suitable recommendation which can be implemented to improve more so that the development and study could help others in many ways. The conclusion of this paper will refer back to the objective of the study where it will discuss whether the target is achieved or not. Besides that, by learning the negative parts of the development, better recommendation could be taken which will improvise the scopes of the study and also the limitations, giving a better result in the future.

5.2 CONCLUSION

In conclusion, the simulation result of the knee joint with healthy and torn meniscus give an idea how important the meniscus towards the knee joint. The healthiness of the meniscus is important for everyone especially for who are active in sport. This study is focuses on two types of kicking that always used by the soccer player which are Inside and Instep kicking. The only difference between the two types of kicking for this study is about the output force after the impact between the foot and the ball. By using the calculated impact force, the force is then be distributed by using certain angles that related to each type of kicking and result with high distributed force comes from the instep kicking. The value used for the simulation process is the highest one which is 371 N.

For the simulation step, a 371 N distributed force is applied through the tibia of the knee joint. The knee joint that consists of femur, meniscus and tibia show the effect after the force is applied. Two cases is being simulated which are knee joint with healthy meniscus and also knee joint with torn meniscus. For the knee joint with healthy meniscus, meniscus is doing its role as the load transmission between the femur and tibia. As shown in Figure 4.3 which is the stress distribution versus the number of node on the tibia, the result shows that the stress value for all of the nodes is in uniform state. The load that is transmitted by the healthy meniscus is in well-mannered shown from the result of the simulation. The range of the stress is in the range of 0.3 MPa to 0.4 MPa. Hence, meniscus is acting like a cushion towards the joint that can prevent an excessive stress happen towards the joint.

Compared with the case of knee joint with torn meniscus, the load that is transmitted by the torn meniscus is not in well-mannered. Although the tear on the surface of the meniscus is small, it is still can affect the meniscus role where the load transmitting purpose is affected. As shown in Figure 4.4 to 4.6, the stress distribution for each figure is not uniform. There is sudden decrease and increase for each node depends on the type of tears. If there is torn in the meniscus, simulation result shows increasing value of stress read on the surface of the tibia. The stress can approach till the maximum value which is 0.5 MPa. Hence, this matter shows that how important the healthiness of meniscus. If there is torn on the meniscus body, an excessive stress may happen towards the knee joint which is one of the most painful someone to bear.

Meniscus is also important towards the knee joint as the knee stabilizer. Healthy meniscus can maintain the stability of the knee joint. Compared with the torn meniscus where the stability of the knee joint is loss because of it. For the simulation result of a full leg with and without knee pad, an external force of 1000 N is applied through the surface of leg skin. The result shows that the force can goes through the internal part of the knee joint and hence give an effect towards the knee joint. Knee joint has bent and cause the meniscus to deform from its original state. Comparing between the leg with and without knee pad, for the leg without knee pad, the deformation of meniscus is greater than leg with knee pad. The meniscus being extrude more since there is no shock absorber attach to the knee when the external force is applied.

5.3 RECOMMENDATION

As for recommendation, some additional recommends may be useful for getting a better and advance result. For the first recommendation, getting raw data from any hospital such as MRI data regarding the meniscus is useful. From the MRI data, the movement of the meniscus within the knee joint can be seen clearly. The data also can be used for the parameter of the simulation, so that the result of the simulation can be more valid.

The other recommendation is, since the meniscus is easily to tear, quick treatment must be carried out in order to prevent it becoming worst. The other way is by doing meniscus replacement. The replacement of the meniscus must be followed like the real one. The shape is also must be in wedges shape. Other than that, finding a material that close one to the meniscus is also important since the meniscus is an element that can be compressed after being loaded.

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Pena, E., Calvo, B., Martinez, M. A., & Doblare, M. (2005). A Three-Dimensional Finite Element Analysis of the Combined Behavior of Ligaments and Menisci in the Healthy Human Knee Joint. *Journal of Biomechanics*. 39(9), pp. 1686-1701

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APPENDIX A

SIMULATION PROCEDURE

1. Ansys Static Structural

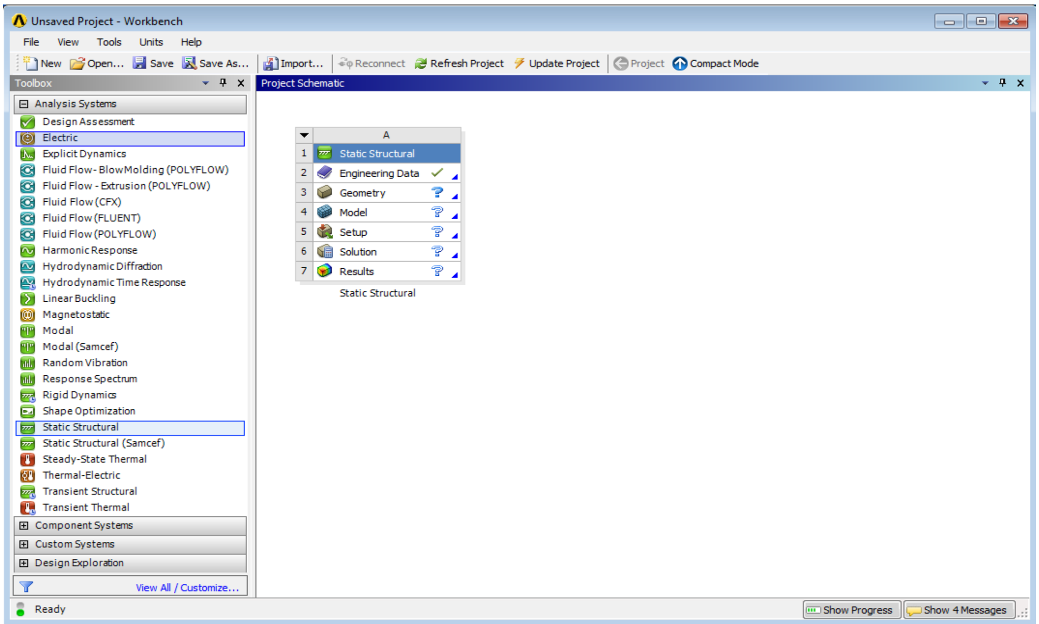

Figure A-1: Ansys Static Structural

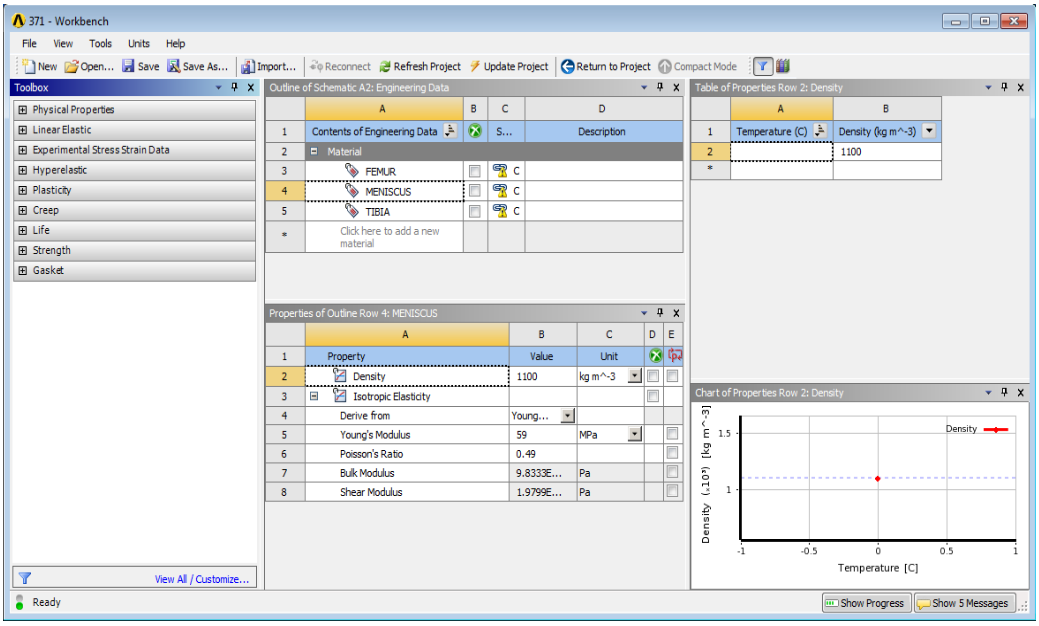

Figure A-2: Set up the Material

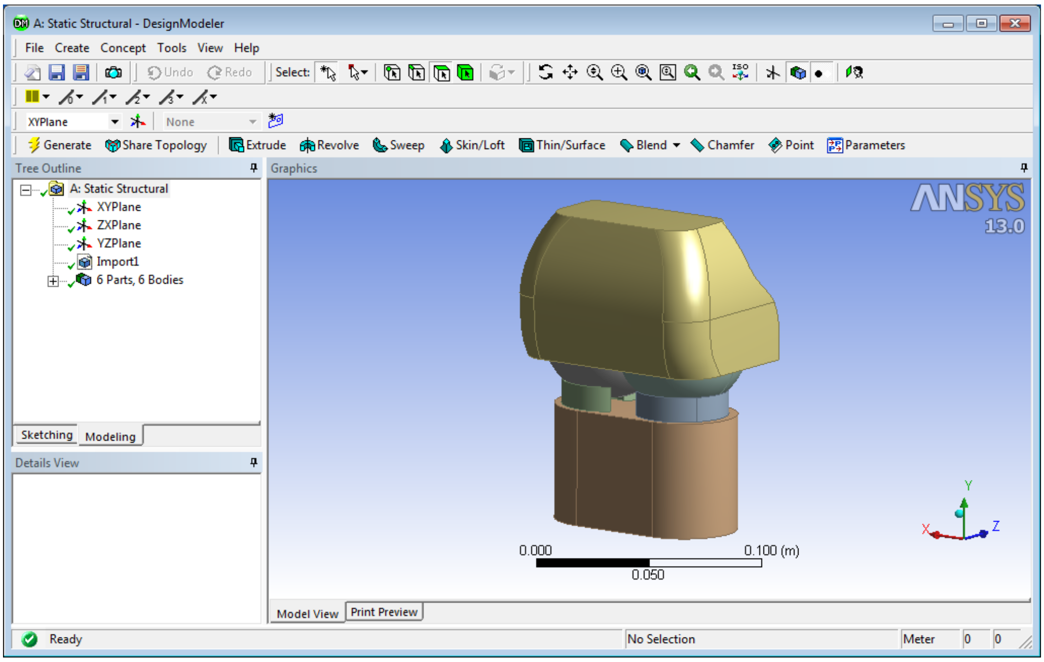

Figure A-3: Importing CAD Design in Design Modeler

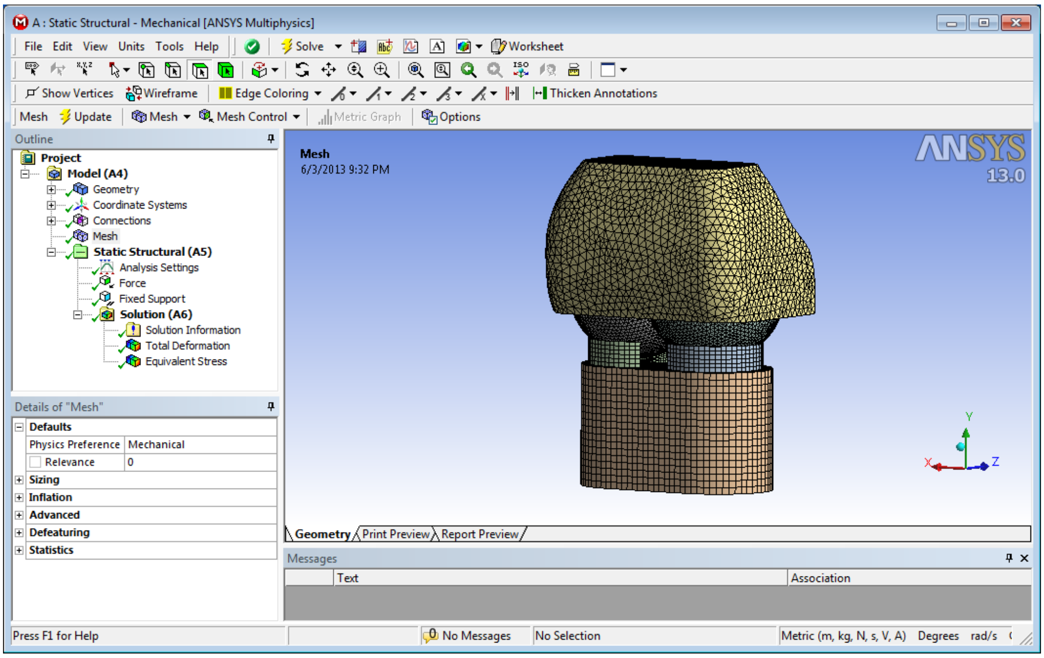

Figure A-4: Meshing the design

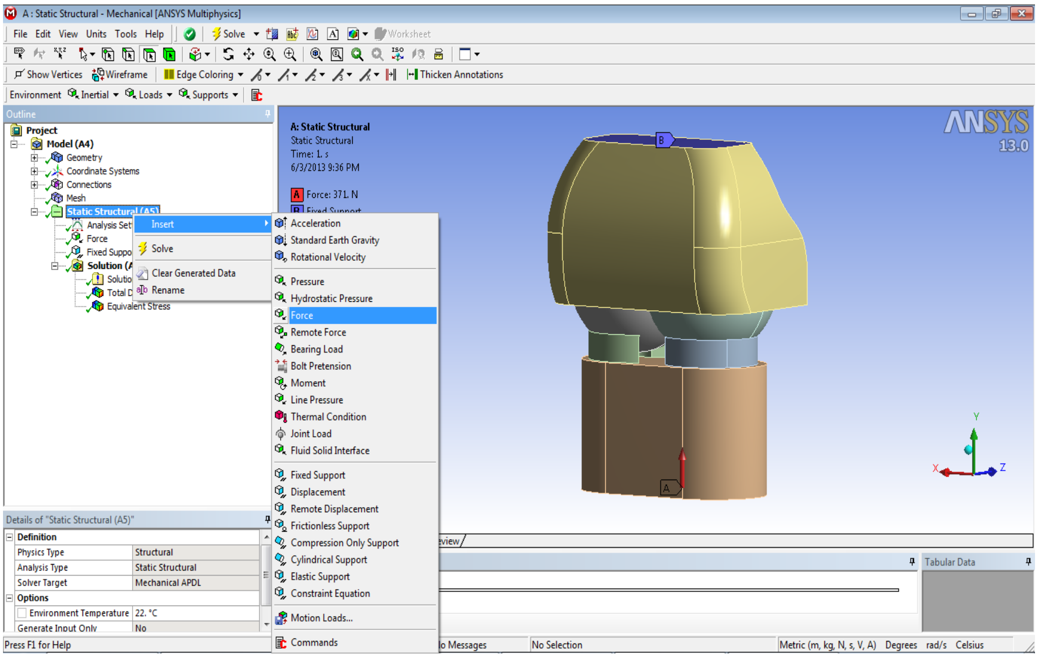

Figure A-5: Set up parameter which is Force

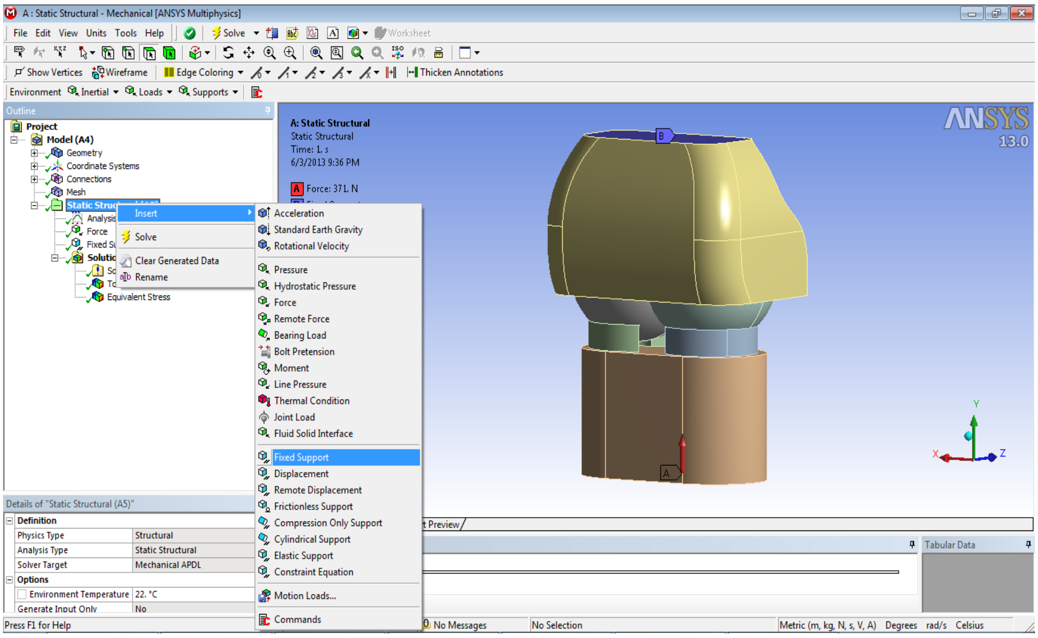

Figure A-6: Set up parameter which is Fixed Support

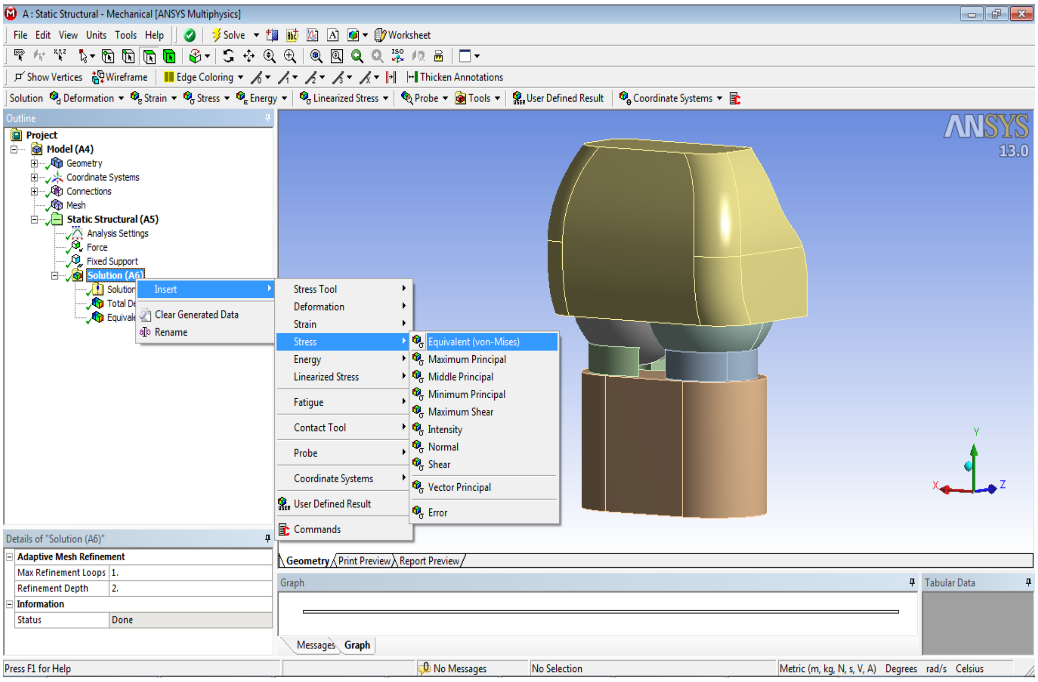

Figure A-7: Selecting type of result

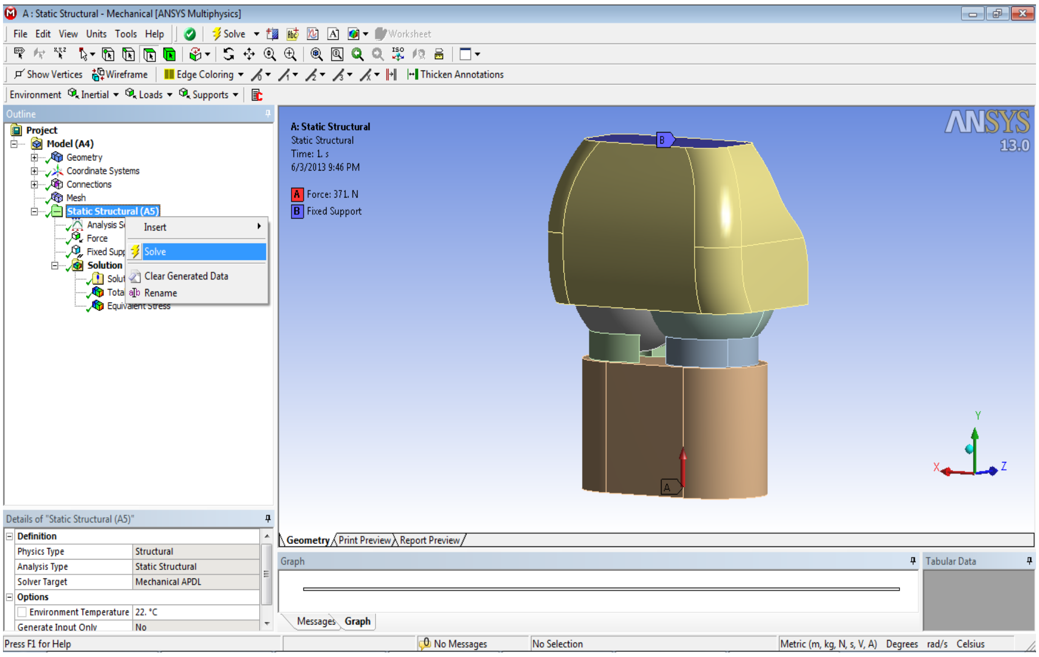

Figure A-8: Start the simulation

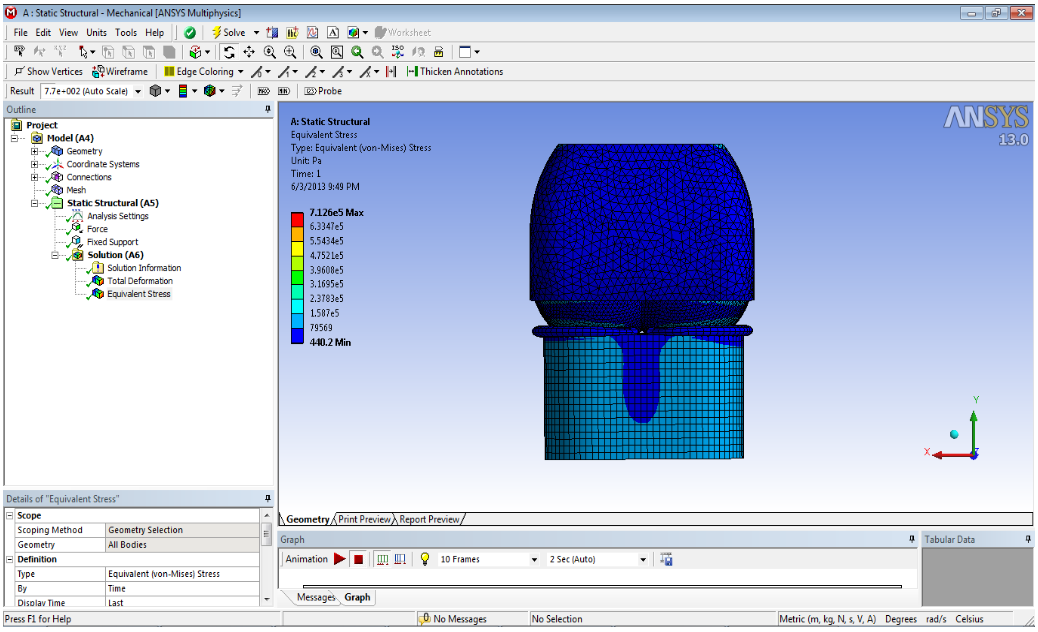

Figure A-9: Simulation result

APPENDIX B

Table B-1: Summary of journals

No	Title of Journal	Method of Journal			Topics			
		Exp	FEA	Theory	Meniscal Function	Meniscal Movement	Meniscal Tears	Soccer Related
1	A Finite Element Analysis of the Human Knee Joint: Menisci Prosthesis Instead of the Menisci and Articular Cartilage		X		X			
2	A Subject Specific Multibody Model of the Knee with Menisci		X		X	X		
3	The Meniscus: Basic Science and Clinical Applications			X	X			
4	Finite Element Analysis of the Meniscus: The Influence of Geometry and Material Properties on its Behaviour	X			X			
5	Meniscal Tear Biomechanics: Loads Across Meniscal Tears in Human Cadaveric Knee	X					X	
6	Finite Element Analysis of the Effect of Meniscal Tears and Meniscectomies on Human Knee Biomechanics		X		X		X	
7	Biomechanics Of The Menisci Of The Knee			X	X	X		
8	Anatomy and Biomechanics of the Meniscus			X	X			
9	Biomechanics Analysis for Right Leg Instep Kick	X						X
10	The Shocking Truth about Meniscus			X	X			
11	The Biomechanics of Kicking in Soccer: A Review			X				X
12	A Three-Dimensional Finite Element Analysis of the Combined Behavior of Ligaments and Menisci in the Healthy Human Knee Joint	X			X			
13	Biomechanical Characteristics and Determinants of Instep Soccer Kick			X				X
14	Meniscal Movement	X				X		
15	Biomechanical Differences in Soccer Kicking with the Preferred and the Non-preferred	X						X

Table B-2: Stress Result for Knee Joint with Healthy Meniscus

	Design 1	Design 2	Design 3	Average
Node	Stress Acted at Tibia	Stress Acted at Tibia	Stress Acted at Tibia	
1	0.40947	0.35927	0.34851	0.37242
2	0.4028	0.3963	0.38174	0.39361
3	0.40468	0.37614	0.37136	0.38406
4	0.41443	0.35692	0.37733	0.38289
5	0.39263	0.36735	0.38995	0.38331
6	0.41393	0.33855	0.3893	0.38059
7	0.42372	0.34893	0.36356	0.37874
8	0.42246	0.35335	0.35946	0.37842
9	0.39127	0.36662	0.36738	0.37509
10	0.40749	0.33208	0.34092	0.36016

Table B-3: Stress Result for Knee Joint with Bucket Handle Meniscus

	Design 1	Design 2	Design 3	
Node	Stress Acted at Tibia	Stress Acted at Tibia	Stress Acted at Tibia	**Average**
1	0.31843	0.48118	0.44878	0.41613
2	0.47457	0.56481	0.40574	0.48171
3	0.31164	0.32409	0.28354	0.30642
4	0.090439	0.059432	0.12218	0.09068
5	0.099654	0.12242	0.093357	0.10514
6	0.098857	0.095921	0.097449	0.09741
7	0.10009	0.11049	0.11158	0.10739
8	0.39	0.4228	0.33284	0.38188
9	0.48138	0.49575	0.43588	0.47100
10	0.35326	0.4393	0.4447	0.41242

Table B-4: Stress Result for Knee Joint with Flap Tear Meniscus

	Design 1	**Design 2**	**Design 3**	
Node	Stress Acted at Tibia	Stress Acted at Tibia	Stress Acted at Tibia	**Average**
1	0.33162	0.38682	0.38666	0.36837
2	0.44904	0.46531	0.39975	0.43803
3	0.44047	0.42485	0.40107	0.42213
4	0.39254	0.40641	0.39646	0.39847
5	0.34073	0.35006	0.37816	0.35632
6	0.34104	0.27511	0.23007	0.28207
7	0.37095	0.35847	0.3439	0.35777
8	0.45754	0.38685	0.3765	0.40696
9	0.45245	0.41938	0.3898	0.42054
10	0.24567	0.36886	0.36849	0.32767

Table B-5: Stress Result for Knee Joint with Parrot Beak Meniscus

	Design 1	**Design 2**	**Design 3**	
Node	Stress Acted at Tibia	Stress Acted at Tibia	Stress Acted at Tibia	**Average**
1	0.31592	0.35475	0.35241	0.34103
2	0.36536	0.37246	0.32491	0.35424
3	0.2735	0.24551	0.22609	0.24837
4	0.2315	0.31602	0.30709	0.28487
5	0.38815	0.41278	0.37039	0.39044
6	0.45224	0.39365	0.41514	0.42034
7	0.4337	0.39298	0.38528	0.40399
8	0.48458	0.39016	0.41538	0.43004
9	0.45975	0.39234	0.41569	0.42259
10	0.23965	0.36999	0.37849	0.32938

Table B-6: Deformation of Wedges and Non-Wedges Meniscus

Node	Wedges Meniscus	Non-Wedges Meniscus
	Deformation	
1	0.02061	0.047608
2	0.027339	0.052022
3	0.035087	0.056366
4	0.04385	0.061401
5	0.05253	0.066836
6	0.062412	0.072819
7	0.071519	0.079684
8	0.08125	0.0865
9	0.090255	0.093014

APPENDIX C

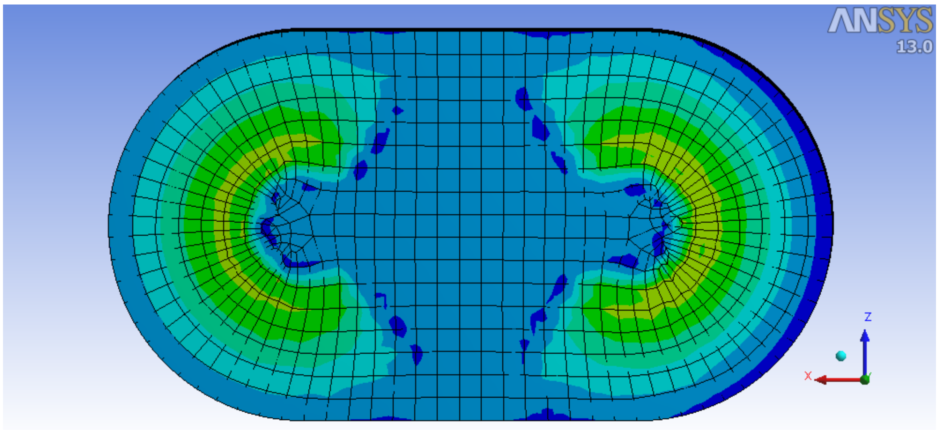

Figure C-1: Knee Joint with healthy meniscus for design 1

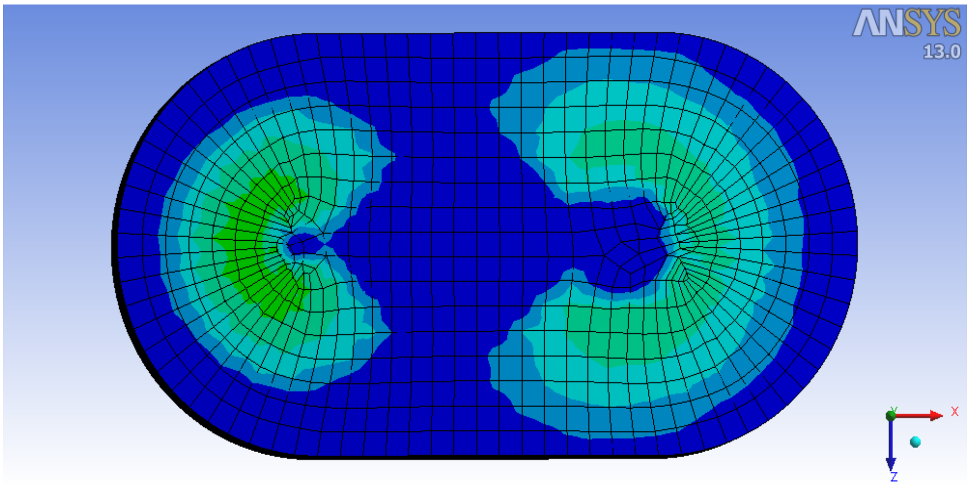

Figure C-2: Knee Joint with healthy meniscus for design 2

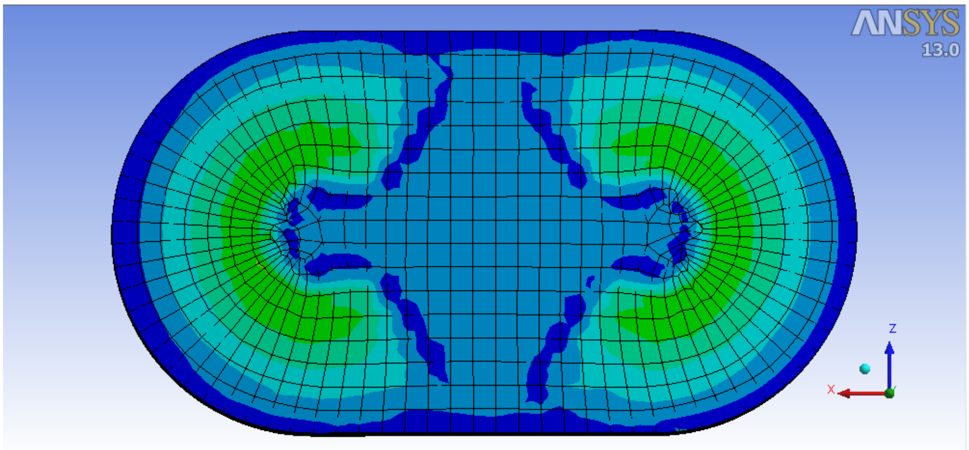

Figure C-3: Knee Joint with healthy meniscus for design 3

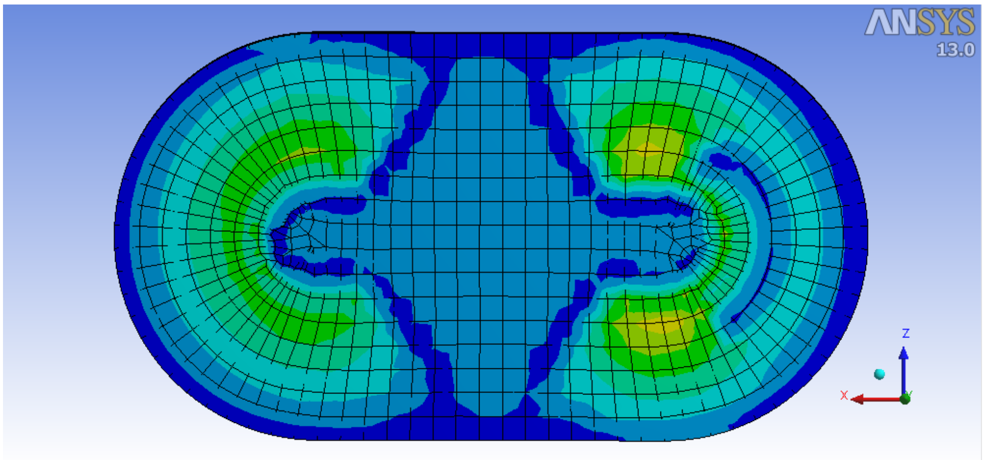

Figure C-4: Knee Joint with Bucket Handle Meniscus for design 1

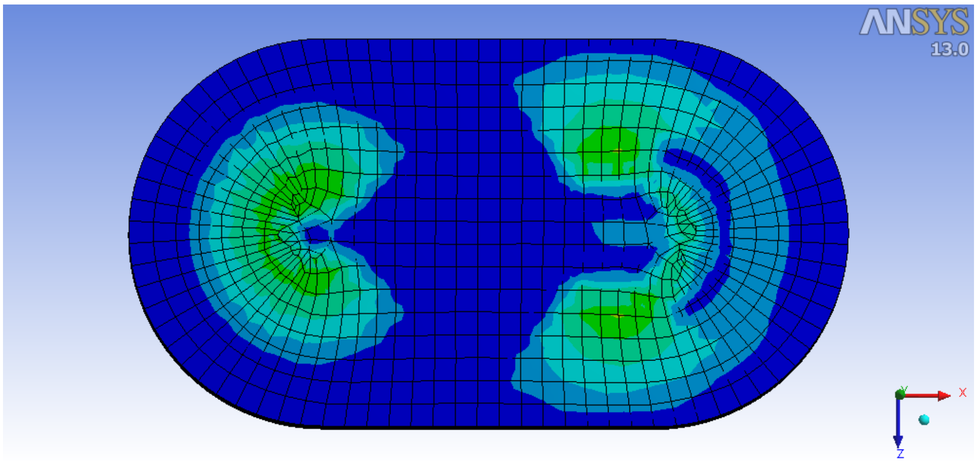

Figure C-5: Knee Joint with Bucket Handle Meniscus for design 2

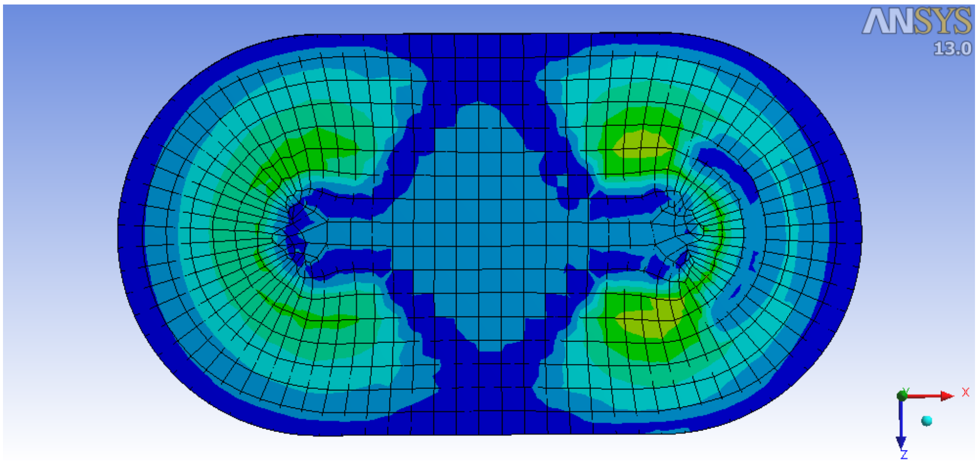

Figure C-6: Knee Joint with Bucket Handle Meniscus for design 3

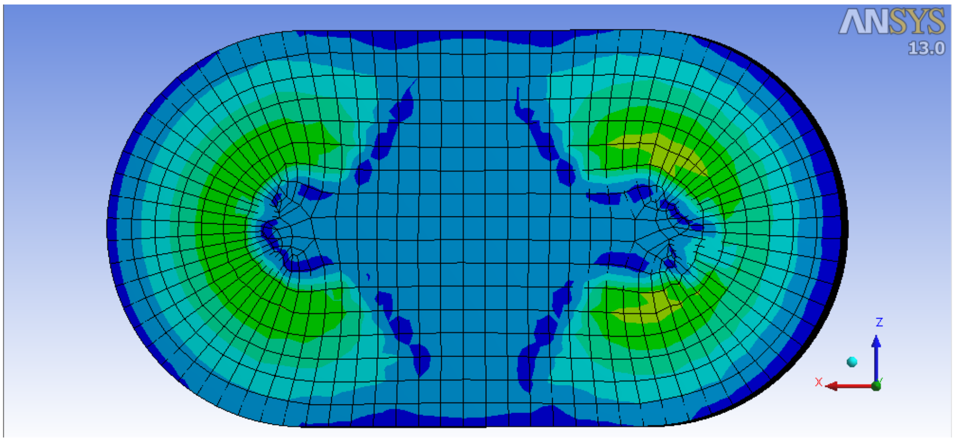

Figure C-7: Knee Joint with Flap Tear Meniscus for design 1

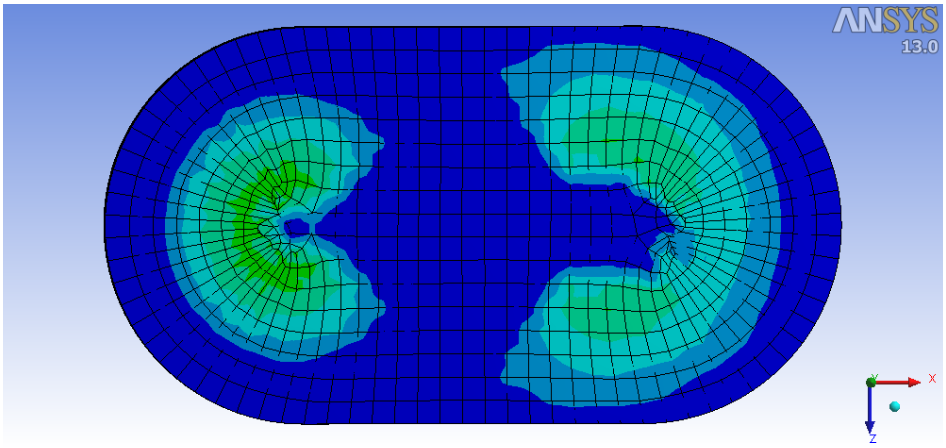

Figure C-8: Knee Joint with Flap Tear Meniscus for design 2

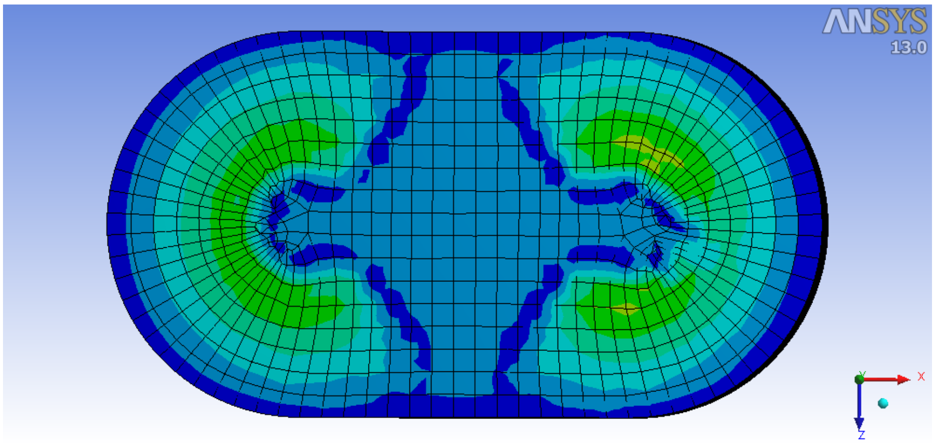

Figure C-9: Knee Joint with Flap Tear Meniscus for design 3

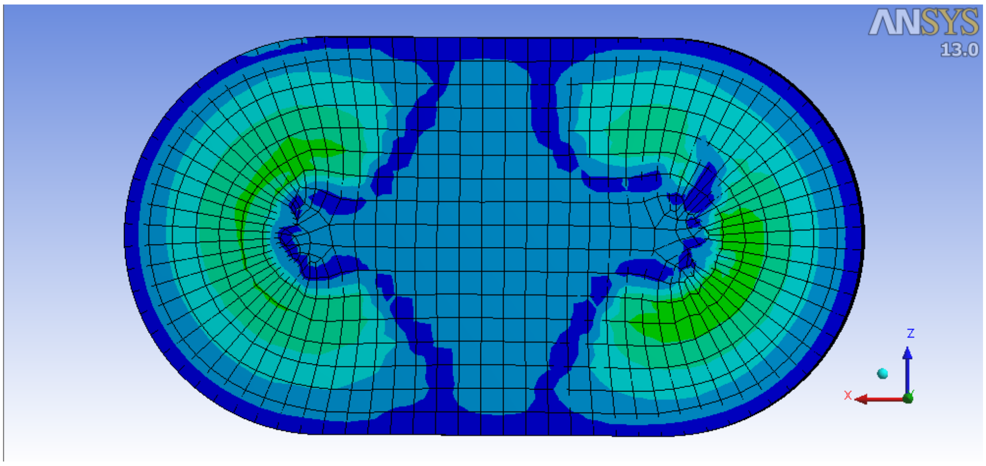

Figure C-10: Knee Joint with Parrot Beak Meniscus for design 1

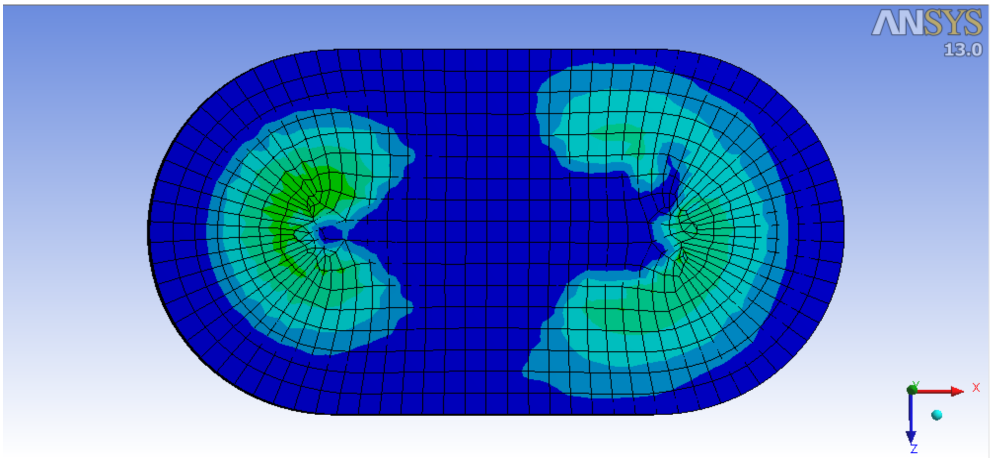

Figure C-11: Knee Joint with Parrot Beak Meniscus for design 2

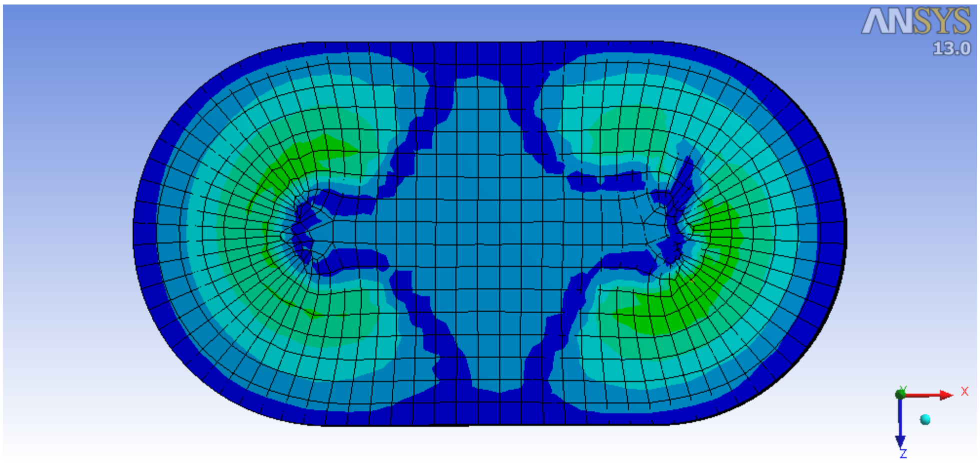

Figure C-12: Knee Joint with Parrot Beak Meniscus for design 3

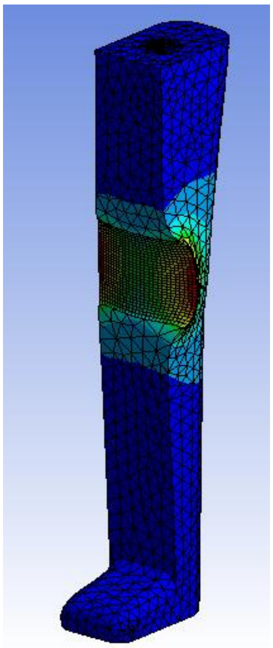

Figure C-13: Simulation of full leg without knee pad

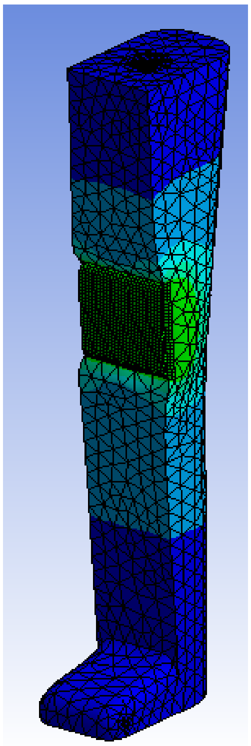

Figure C-14: Simulation of full leg with knee pad

APPENDIX D

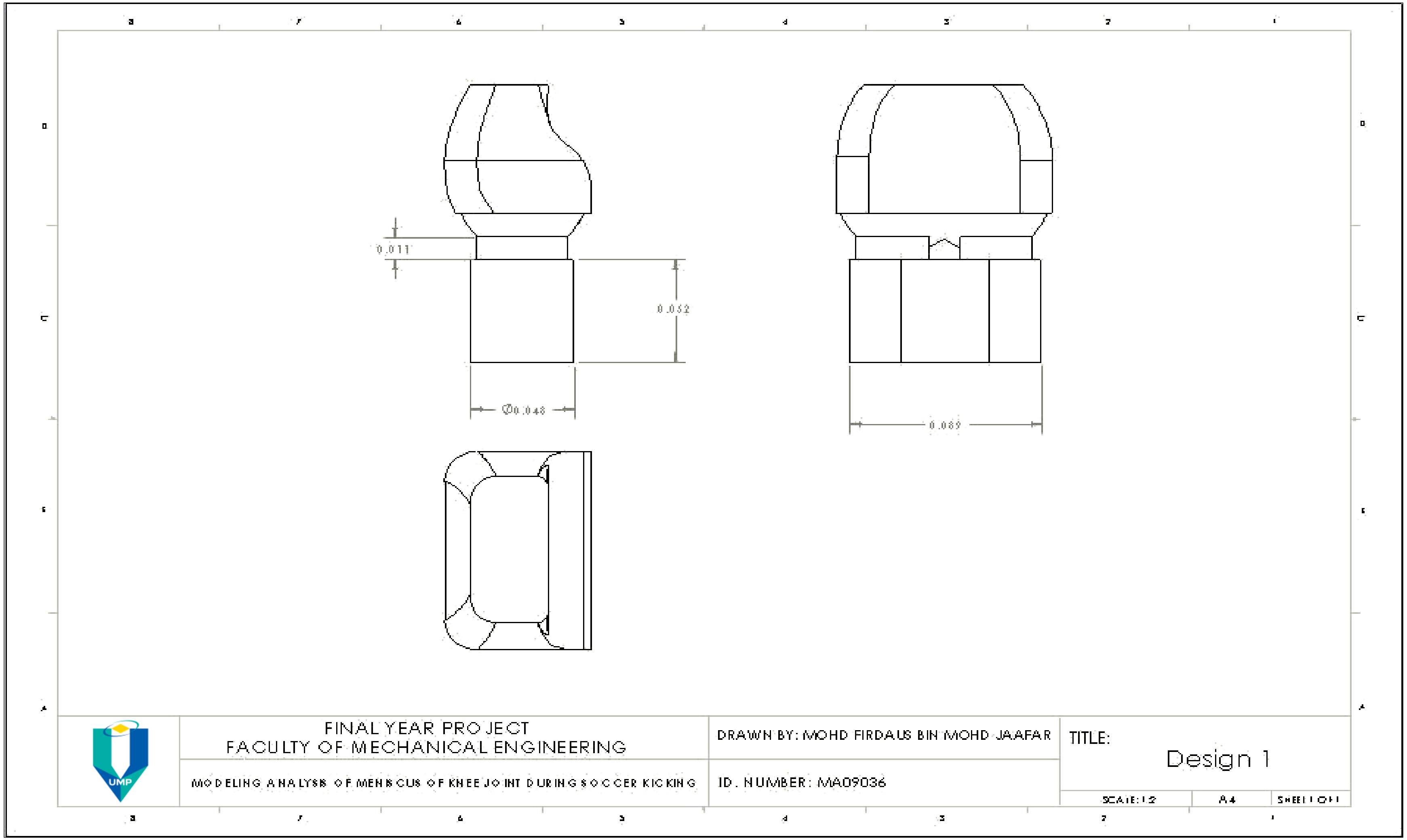

Figure D-1: Design 1

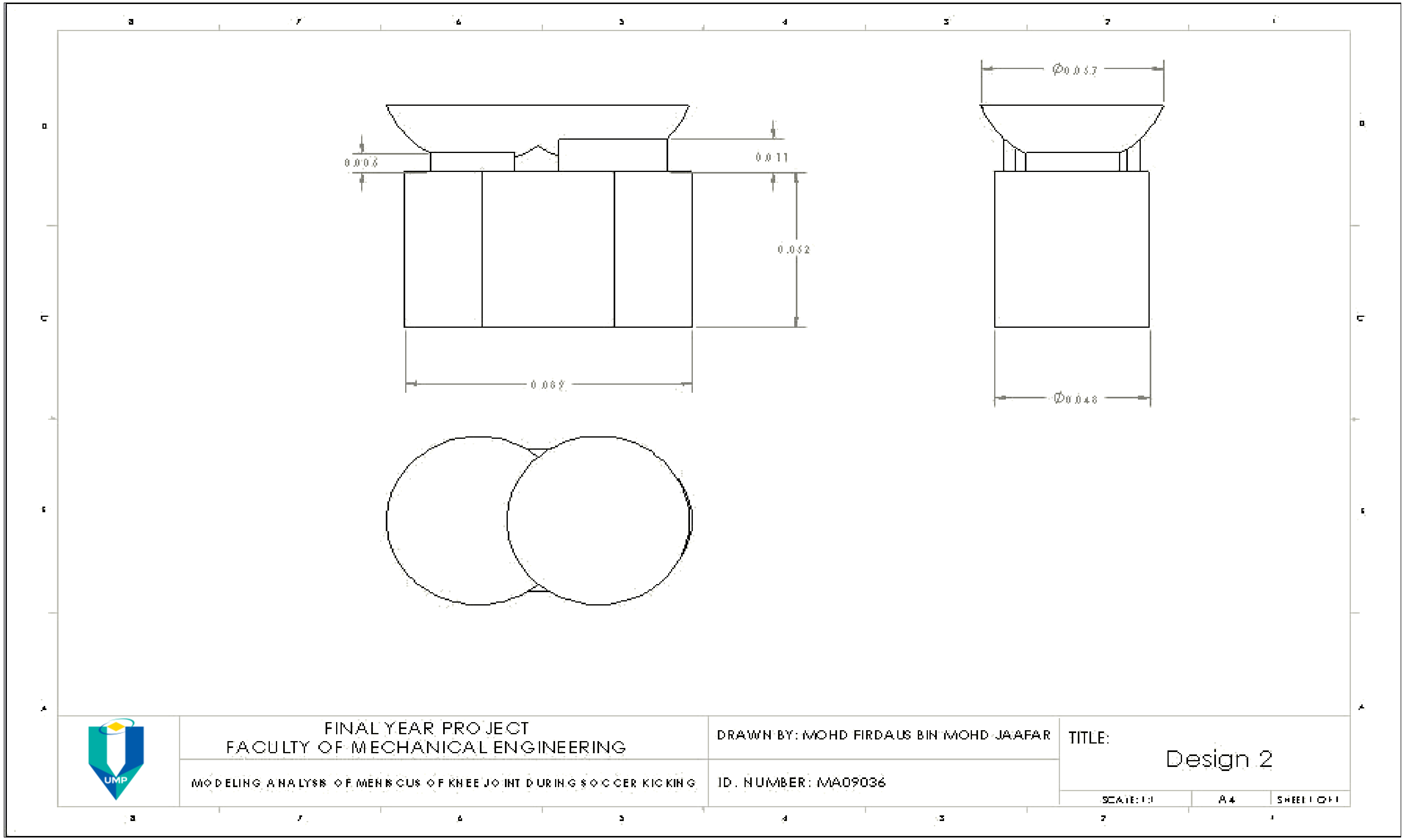

Figure D-2: Design 2

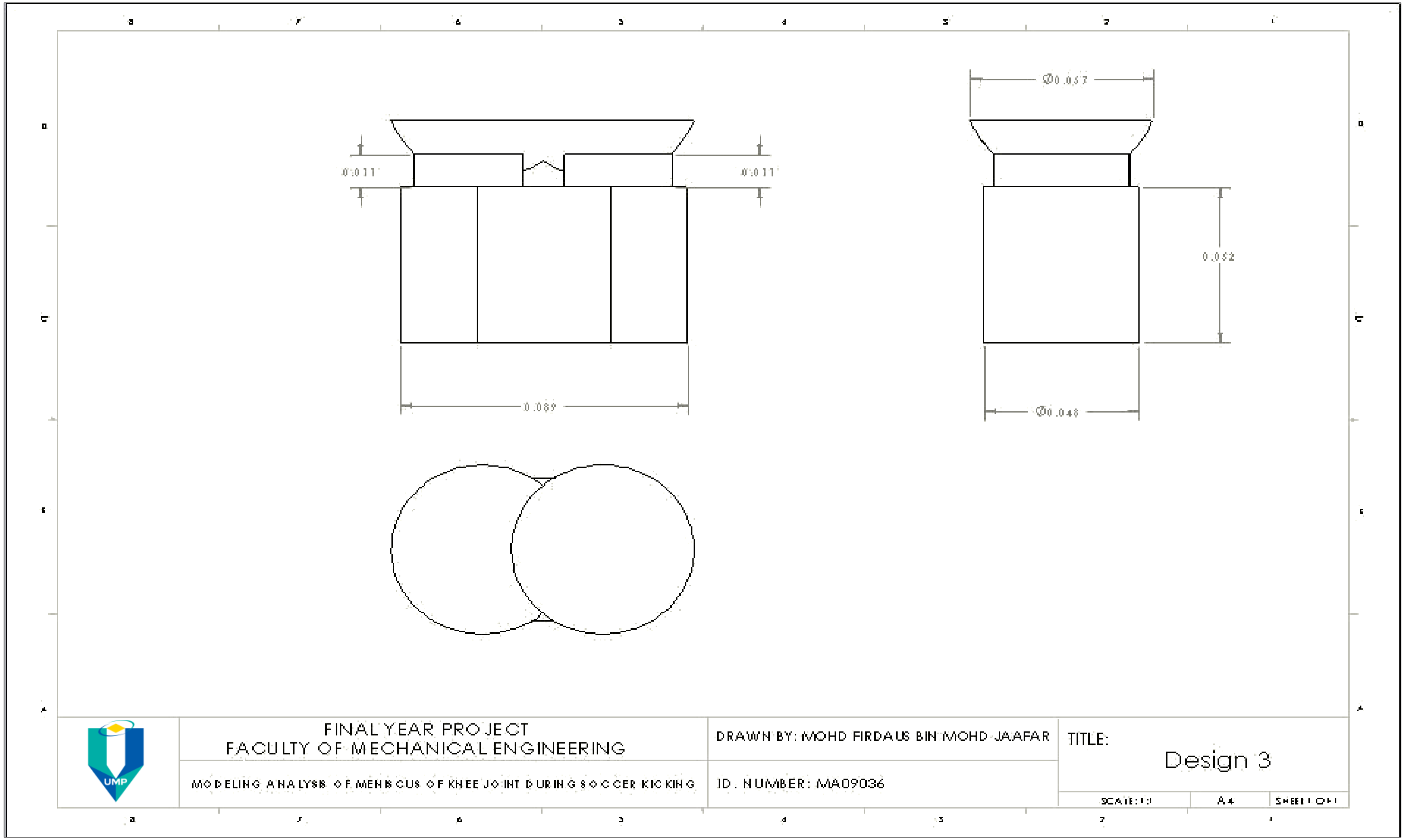

Figure D-3: Design 3

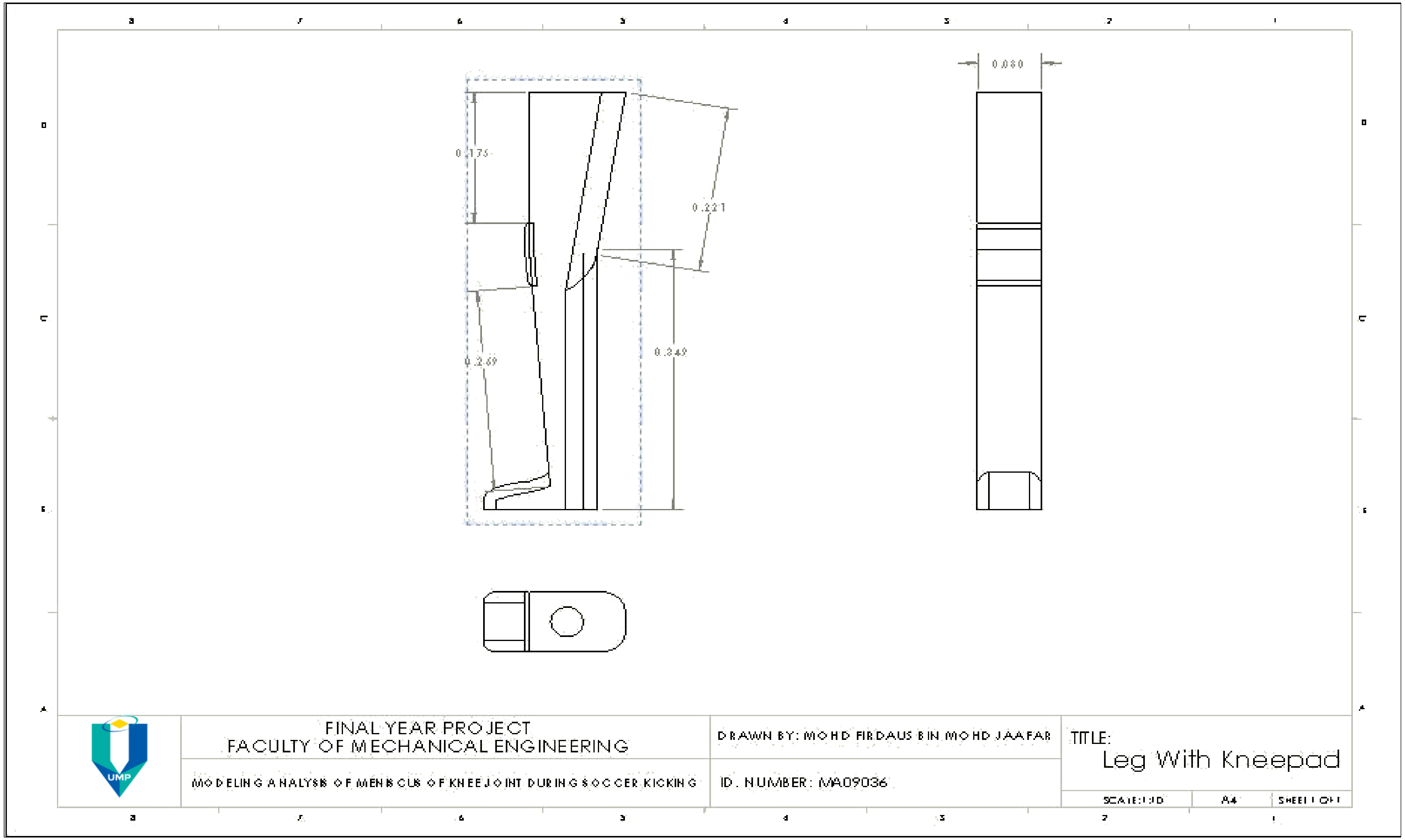

Figure D-4: Leg With Kneepad

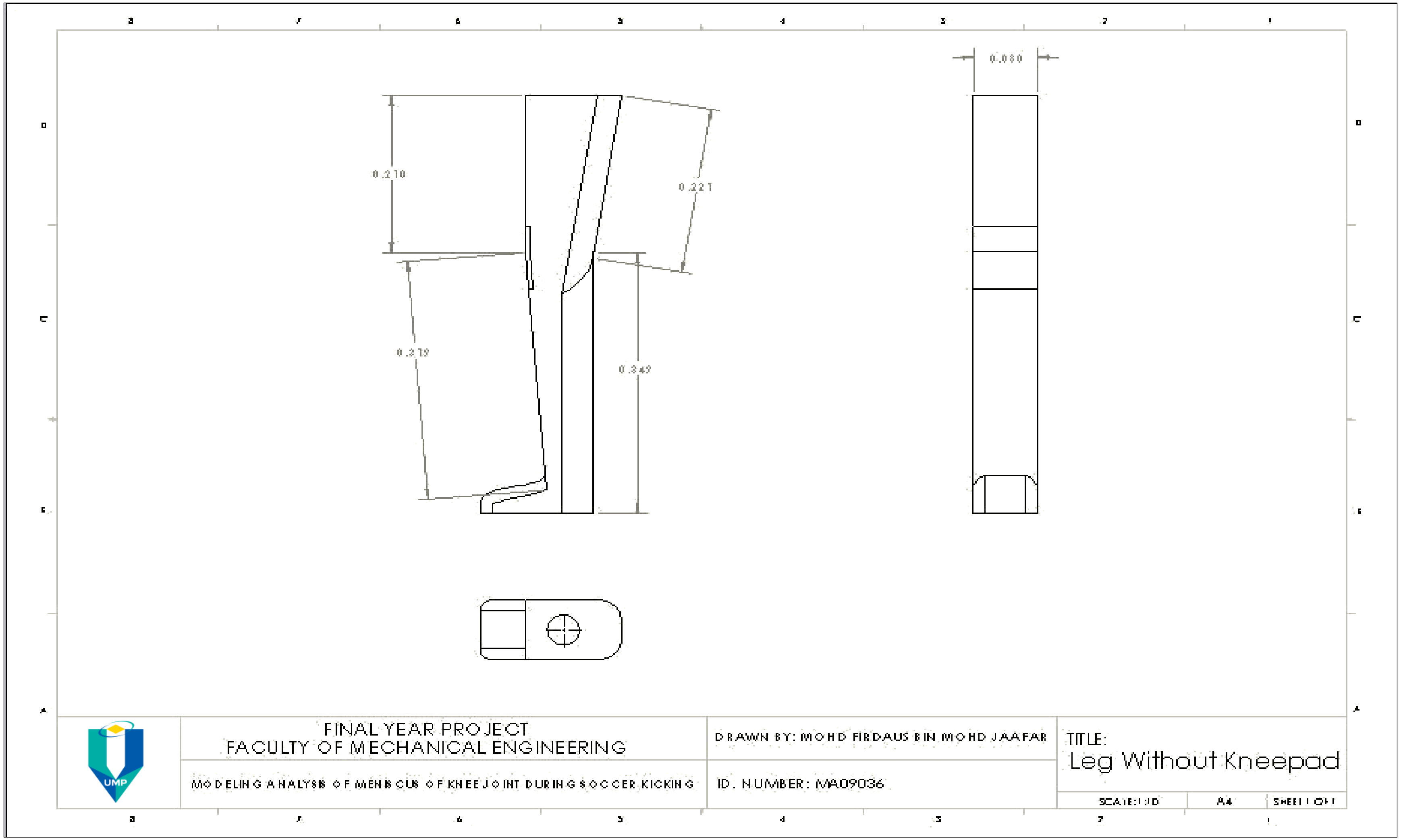

Figure D-5: Leg Without Kneepad

APPENDIX E

GANTT CHART FOR FINAL YEAR PROJECT 1

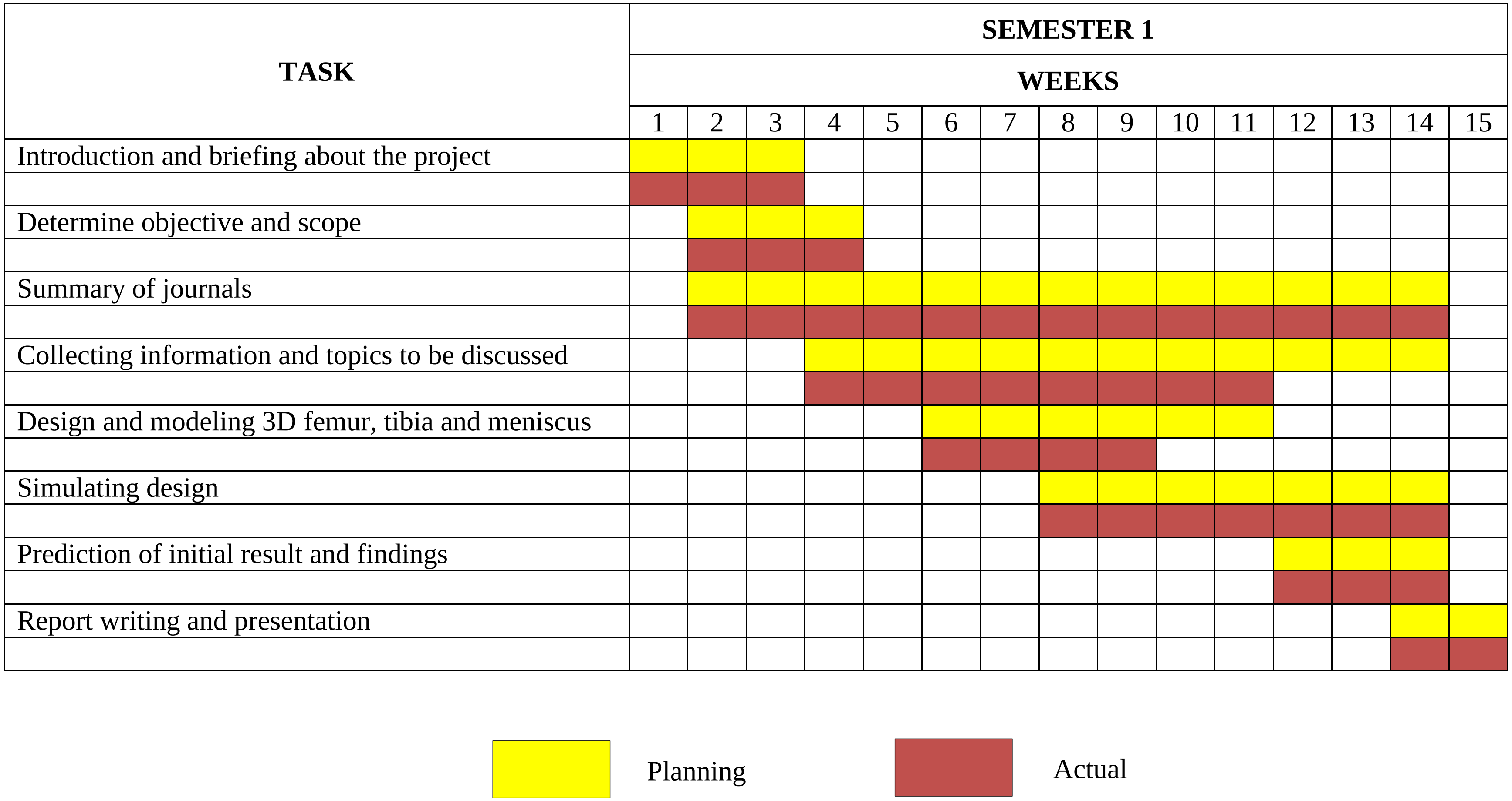

Figure E-1: Gantt chart for Final Year Project 1

GANTT CHART FOR FINAL YEAR PROJECT 2

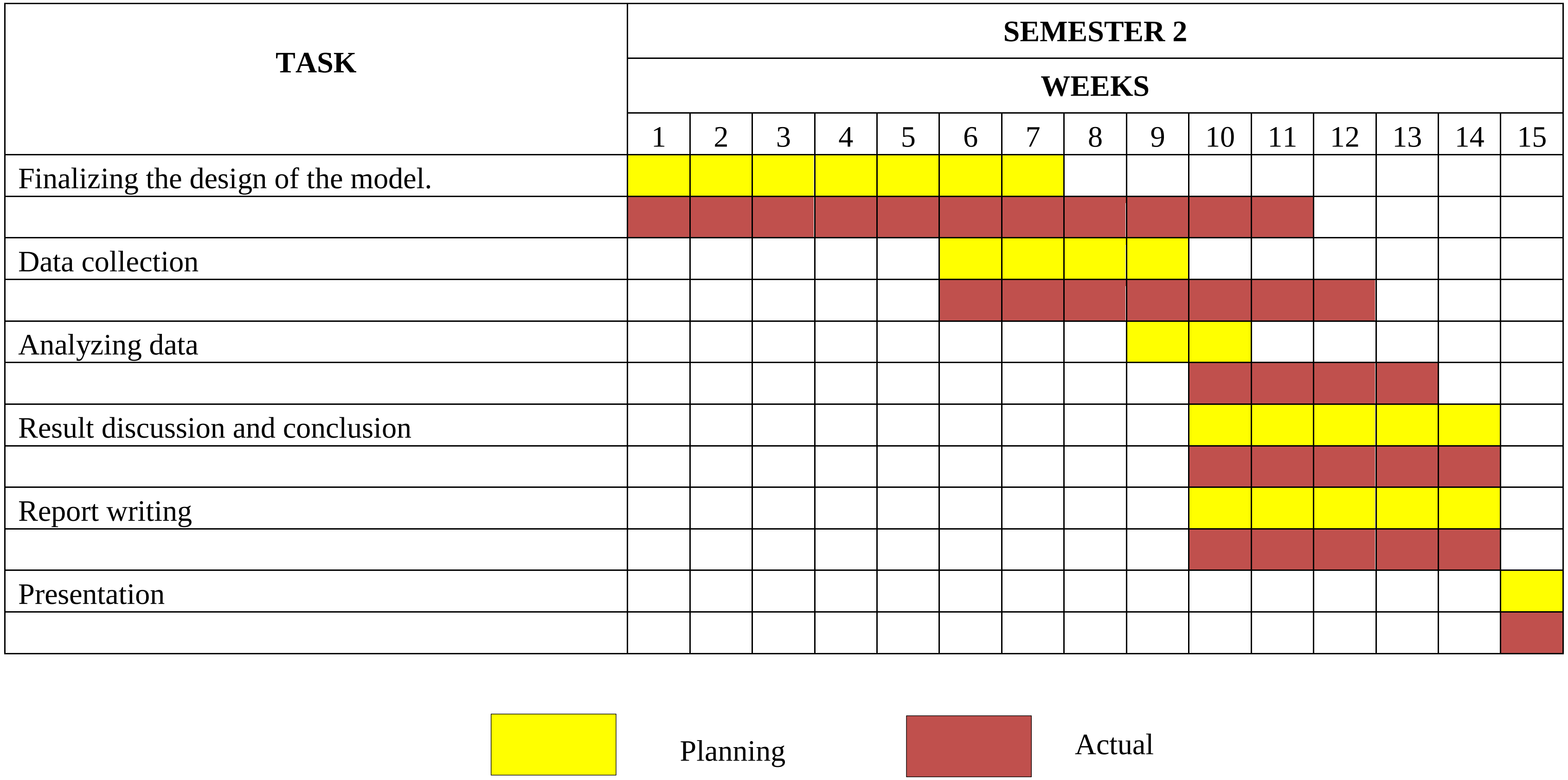

Figure E-2: Gantt chart for Final Year Project 2