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I hereby declare that I have read this thesis and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure and Materials).

SIGNATURE : ....

NAME : DR MOHD JUZAILA BIN ABD LATIF

DATE :

MODELLING AND STUDY OF FEMUR BONE UNDER NORMAL LOADING

HAZ'ZAID BIN ABDUL MU'IN

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30 MAY 2012

DECLARATION

"I agree that this report is my own work excepted for some summaries and citation which I have already stated"

SIGNATURE : ....

NAME : HAZ'ZAID BIN ABDUL MU'IN

DATE : 30 MAY 2012

Specially dedicated to my loving parents,

My great and good-hearted supervisor,

my cheerful siblings and my supportive friend.

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ABSTRACT

As human walking, running, or standing, normal forces will act on the femur bone to make them balance. Healthy and non-healthy bones have different stress distribution internally. In order to identify the area of the maximum stress on each bone, the stress distribution of the bones is investigated. Validation of the modelling method was performed using a simplify 3D model of femur bone and next being analyzed by using finite-element software. After that, the result will be compared with the theoretical calculation of normal loading. After the method is validated, stress distribution of both hollow and solid femur bone will be analyzed by using the same method of analysis. All the maximum stress will be determined. Other than that, mesh sensitivity analysis is conducted to get the optimization value for the number of mesh. All the results are stated in the result chapter. Lastly, after the result is satisfied, all data that investigated will be discussed and then a conclusion will be stated.

ABSTRAK

Apabila manusia berjalan, berlari, atau berdiri, daya normal akan bertindak pada tulang femur untuk membuat mereka seimbang. Tulang yang sihat dan tidak sihat mempunyai agihan tegasan yang berbeza. Untuk mengetahui kawasan tegasan maksimum pada setiap tulang, agihan tegasan tulang disiasat. Untuk mengesahkan kaedah analisis, model 3D tulang femur yang telah dipermudahkan dihasilkan dan seterusnya dianalisis dengan menggunakan perisian unsur terhingga. Selepas itu, hasilnya akan dibandingkan dengan pengiraan teori beban biasa. Selepas kaedah ini disahkan, agihan tegasan kedua-dua tulang femur berongga dan pepejal akan dianalisis dengan menggunakan kaedah yang sama. Semua tegasan maksimum akan ditentukan. Selain daripada itu, analisis sensitiviti jaringan dijalankan untuk mendapatkan nilai pengoptimuman bagi bilangan jaringan. Semua keputusan telah dinyatakan dalam bab keputusan. Akhirnya, selepas mendapat keputusan yang memuaskan, semua data yang disiasat akan dibincangkan dan kesimpulan akan dinyatakan.

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1.1 Introduction

The Femur bone is one of the strongest bones that placed on the lower part of the human body. The bone connects with the tibia bone to form the knee joint. Although it is one of the strongest bones, it also exposes to fracture injuries. Injuries that are usually occurred in the femur bone is important to be analyzed. Therefore, investigation on the mechanism of the injury and the stress that acted on the bone is essential so that it can be diagnosed, and several solutions of treatment can be determined. Many experiments have been conducted to obtain data for future studies. Nowadays, there are many surgical techniques developed to treat the injuries. Experiment studies have been carried out in order to evaluate stresses on femur bone.

1.2 Femur bone

Femur bone in Figure 1.1 is divided into two extremity parts. It is upper extremity and lower extremity region. Both extremities connected via a shaft. In upper extremity, it includes the head, the neck, greater trochanter and lesser trochanter. Meanwhile, for the lower extremity, it includes patellar surface, lateral condyle, and medial condyle. All the parts have it function to support the human body (Gray & Henry, 1918)

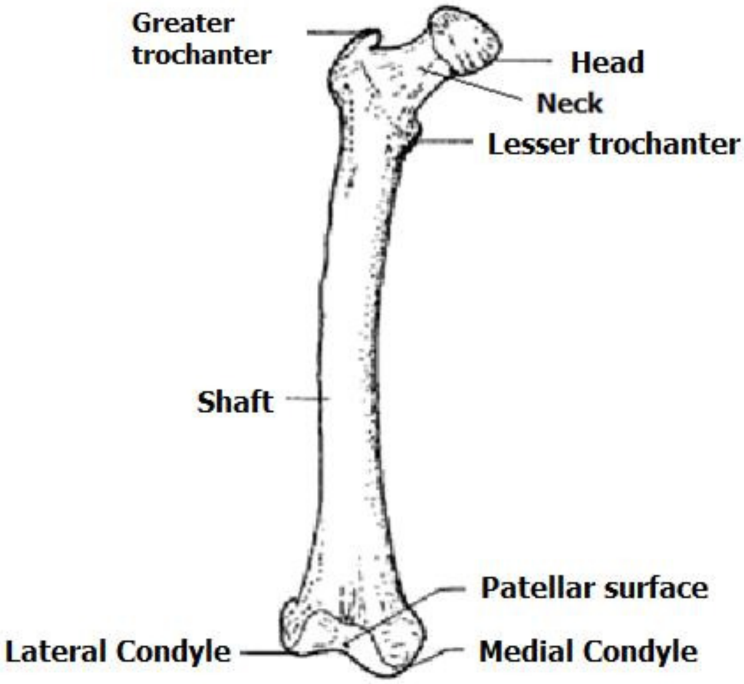

Figure 1. 1: Femur bone. Adapted from (Gray & Henry, 1918)

1.2.1 Head

The head that has a spherical shape form, facing upward and a bit forward has a major part of its convexity being above and in front. The surface on the head is smooth, and it is coated with cartilage in the fresh state (Gray & Henry, 1918). If the heads are experience depression, the fovea capitis femoris, which is located a little below and behind the center at the head, and gives attachment to the ligamentum teres (Gray & Henry, 1918).

1.2.2 Neck

The neck is located between the head and the main part from the femur bone. The neck is connecting the head with the body, and forming a wide angle of medialward opening with the latter. In early growth of the human body, the angels whom the neck made are the widest, later, it will become smaller (in angle) during humane growth. (Gray & Henry, 1918).

During the human reach puberty, it will form a gentle curve from the axis of the body of the bone. When the humans are in adult, the neck will form approximately 125 degrees from the body. (Gray & Henry, 1918)

However, the angle at the neck will vary slightly due to the development of the pelvis and the stature. For female, due to the development of the pelvis that is becoming wider, the angle formed is approximately a right angle that is perpendicular to the body if comparing to the normal male growth. As stated earlier, the angle growth will decrease due to the human growth. (Gray & Henry, 1918)

However, as after the human body experiences the full growth, the angle will no more intend to change. During old age, the angle still varies slightly for each person of the same age. In addition to projecting upward and medialward from the body of the femur, the neck also projects somewhat forward. The amount of changes in angle of the neck cannot be specified (Gray & Henry, 1918). Nevertheless, it is roughly in average of 12 degrees until 14 degrees.

1.2.3 Trochanters

There are two types of trochanters on the femur bone, and it is greater trochanters and lower trochanters. Greater trochanter has more surface area than the lesser trochanters (Gray & Henry, 1918). The function of these trochanters is extremely affording support to the leg muscles that rotate the thigh on its axis.

1.2.4 Shaft

The shaft is the biggest part in the femur bone. The shape of the femur shaft is almost cylindrical. From the upper part from the shaft, it will decrease in diameter until to the center (Gray & Henry, 1918). Then from the center it will somewhat be flattened from before and become larger downward.

From the front view of the femur bone, it is slightly curved, convex in front, and concave behind. The shaft is strengthened by a major longitudinal edge called the linea aspera. The linea aspera is presents for separating three surfaces. The surfaces are posterior, medial and lateral (Gray & Henry, 1918)

1.2.5 Patellar surface

The patellar surface is formed between the anterosuperior parts of both femoral condyles that provide loading to the patella (Gray & Henry, 1918).

1.2.6 Lateral Condyle and Medial Condyle

The lateral is located at the lower part from the femur bone. It is the border in its antero-posterior, and transverse diameters compare to the other condyle. (Gray & Henry, 1918). The medial condyle is one of the two projections on the femur. More forces acted on the medial condyle due to the center of gravity being medial to the knee (Gray & Henry, 1918). Therefore, the shape of the medial condyle is larger than the lateral condyle.

1.3 Structure and Properties of Femur Bone

Bones are made from a process called ossification. The process is whereby cartilage is turned into bone. The Cancellous bone (spongy bone) and cortical bone (compact bone) are made from the process. The cancellous bone is located inside the cortical bone layer as in Figure 1.2.

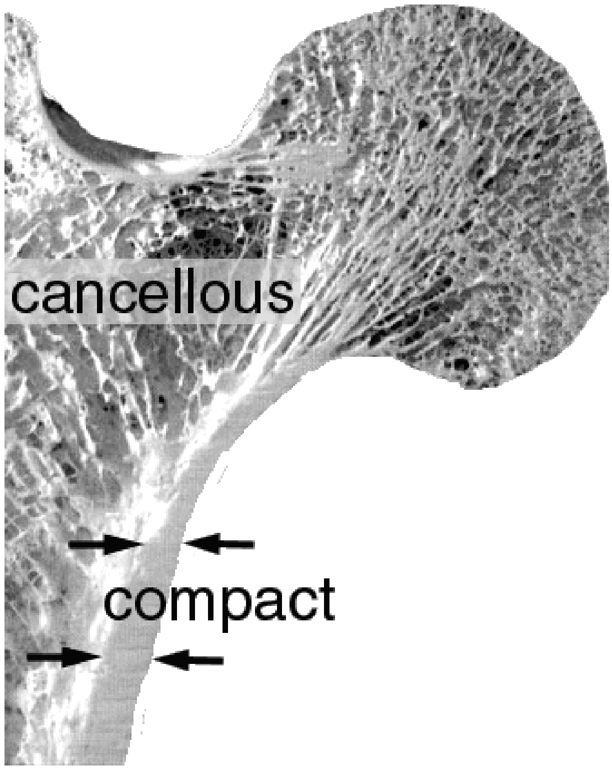

Figure 1. 2: Compact bone and cancellous bone. Adapted from https://courses.stu.qmul.ac.uk

1.3.1 Cancellous bone (Spongy bone)

The exact location of the spongy bone is on the upper femur (includes head and neck region) until the lesser trochanter region. Two distinct systems cancellous are arranged in a curved part inside the femur bone.The first one at the inner portion of the shaft and it is curving upward shaped like a fan radiation symbol that is opposite to the other side the bone. The other one is having at the outer portion of the shaft and growth upward and medially to the end of upper surface of the greater trochanter, neck and head. Both systems are intercepting with each other at the right angle (Gray & Henry, 1918).

In the spongy bone there contains a red bone marrow functioned to make red blood cells. Then, in the marrow cavity contain yellow marrow that makes white blood cells.

1.3.2 Cortical bone (compact bone)

The cortical bone is located outer side the femur bone. The main function the bone is to support the whole body due to its high strength and denser that cancellous bone. The cortical bone contributes approximately 80% of human skeleton. The primary anatomical and functional unit of the bone is the osteon.

1.4 Forces acted on the femur bone

From previous study, it is concluded that load that acted on the femoral head lead the femur bone to experience bending when the compression force is applied (Taylor, et al., 1995).

Forces that acted on the head of femur bone are only joint reaction force and some additional abductor muscle force. Both forces result from a bending force against the femur bone. Although the forces that acted on the femur bone can be estimated, and the direction can be determined, but the true magnitudes of forces during various activities are yet to be properly defined (Taylor, et al., 1995).

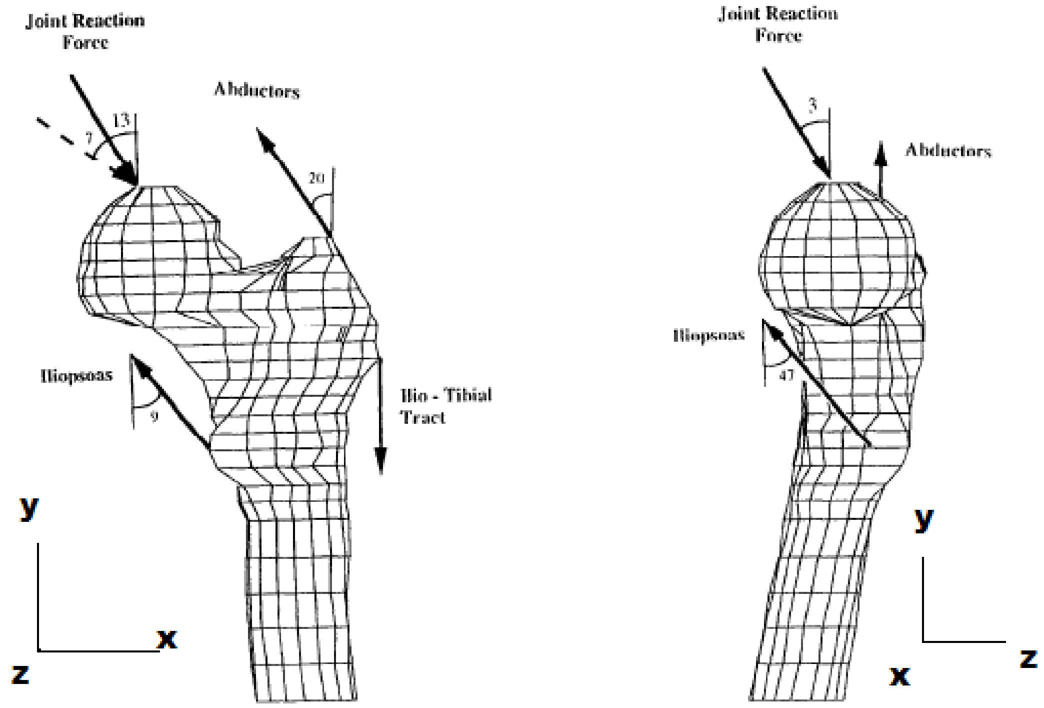

Figure 1. 3: Forces that acted on the upper extremity of the femur bone. Adapted from (Taylor, et al., 1995)

The bone was assumed to be linearly elastic, homogeneous and isotropic material properties throughout. The distal end to the femur bone was generated in Abaqus software. Next, the joint reaction of 3kN was selected acted on the femoral head in 13-degree direction. Then, mass of 70kg is applied on it. For the Young Modulus value, it was assumed 17 GPa and the Poisson's ratio was 0.33. The result only for femoral head is recorded in the table. (Taylor, et al., 1995);

Table 1. 1: Muscle and joint reaction force. Adapted from (Taylor, et al., 1995)

Load case number	Force X kN	Force Y kN	Force Z kN	Resultant kN
Joint reaction force	0.616	-2.800	0.171	2.872
Abductors	-0.430	1.160		1.237

Focusing on the joint reaction force that acted on the femoral head, the resultant force is in positive value. It means that the force that acted on the femoral head is a compression force. As the load is predominately in compression on the bone, from a various analytical study, it is indicated that the femur bone would experience bending. A large deflection on the femoral head or some significant degree of curvature of the femoral shaft will occur. Average medial deflection of femoral deflection was 1.25mm and the average vertical deflection was 1.5mm. All the value indicated that the femur bones are loaded extremely in compression. (Taylor et al., 1995)

1.5 Stress distribution on femur bone

From the previous study (Wagner, et al., 2010), the research has shown that the Von Mises stress that acted on the bone while walking. The stresses are shown in the figure 1.4.

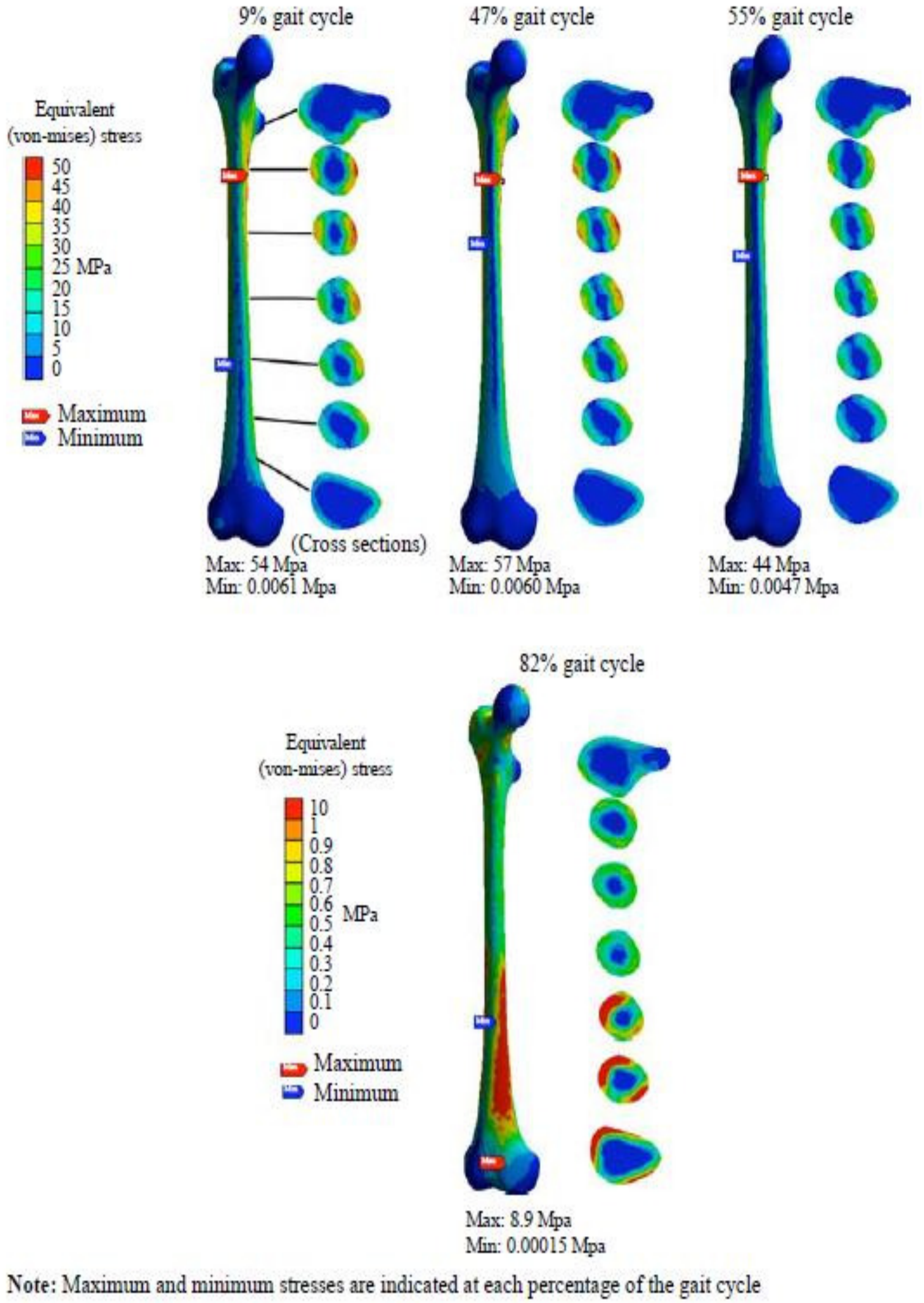

Figure 1. 4: Von Mises stress distribution inner and outer of the femur bone. Adapted from (Wagner et al., 2010)

The maximum stresses that shown are mainly on the shaft of the femur bone. This is due to the lower extremity become the boundary condition while the forces are applied on the head of the femur bone. Therefore, the region to have a high tendency to fail is on the shaft region. During standing, the stress will evenly distribute trough out the femur bone. During this condition, the neck area and the shaft area will have the higher maximum stress then other region.

1.6 Traumas of Femur Bone

Due to its physical properties that are brittle and strong, femur bone can experiences crack, wear or fractures if external force is acted on the femur bone larger than its maximum load stress of yield stress. Several traumas related to the femur bone.

1.6.1 Neck trauma

One type of neck trauma is arthritis disorder. This is a joint disorder featuring inflammation. A joint is an area of the body where two different bones meet. A joint function is to move the body parts connected by its bones. Arthritis literally means inflammation of one or more joints. (Orthop, 2011)

The most famous treatment for arthritis disorder is total hip replacement. The treatment is using‘ball and socket’ concept where by the defected cartilage and bone of the hip joint is replaced with artificial materials. This surgery is conducted by removing the defected ball and replaced it with a metal ball and a stem (prosthesis). The artificial ball and socket will be inserted surgically into the femur bone while an artificial plastic cup socket will replace the acetabulum as figure 1.5. By replacing the prosthesis into the central core of the femur, it is fixed with bony cement called methyl methacrylate. For younger patients, it is better for using a