UNIVERSITÉ DE STRASBOURG

Advanced utilization of computational solid mechanics

ABAQUS

Evaluation 1

Stress analysis of a prothestic implant with ABAQUS/CAE

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INTRODUCTION

Hip replacement

Hip replacement is currently the most common orthopaedic operation. Hip replacement is a surgical procedure in which the hip joint is replaced by an prosthetic implant.

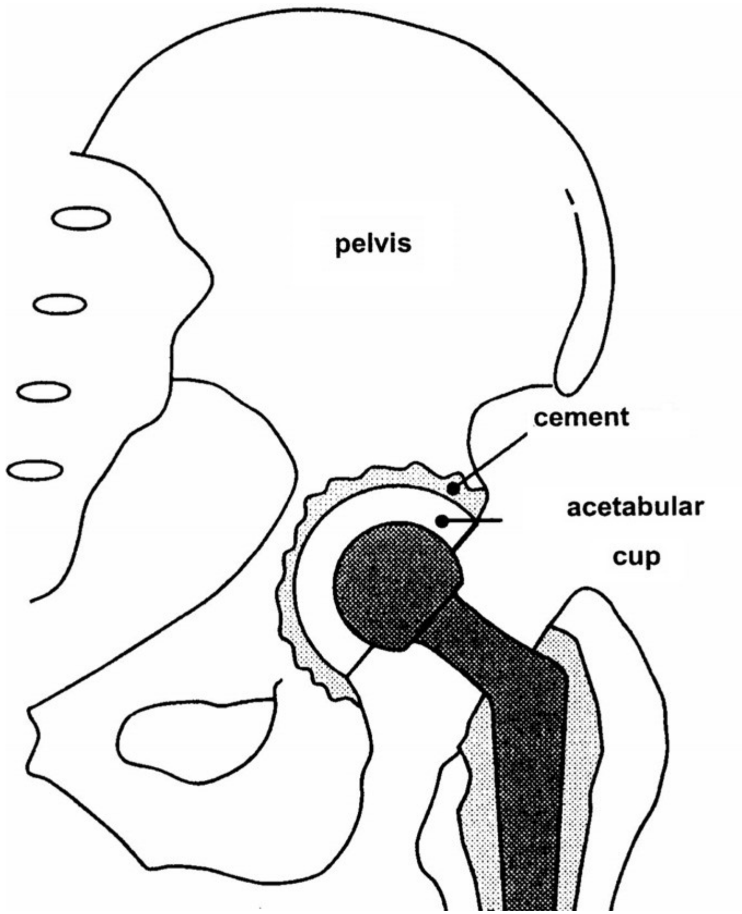
Prosthetic implants are intended to support forces and must thereby be firmly attached to the rest of the skeleton. The implant is placed in the body either with an acrylic cement that gradually fails as regeneration of connecting bone tissue is proceeding, or without cement using an implant with an interface designed to provide the necessary attachment. Cemented implant is used in the majority of operations.

(Wikipedia, the free encyclopedia)

The prosthetic implant used in hip replacement consist of different parts : the acetabular cup, the femoral component and the articular interface.

The Acetabular cup is the component which is placed into the acetabulum (hip socket). Cartilage and bone are removed from the acetabulum and the acetabular cup is attached using friction or cement.

The femoral component is the component that fits in the femur (thigh bone). Bone is removed and the femur is shaped to accept the femoral stem with attached prosthetic femoral head (ball). There are two types of fixation: cemented and uncemented.



(Zant *et al.*, 2007)

MODEL DESCRIPTION

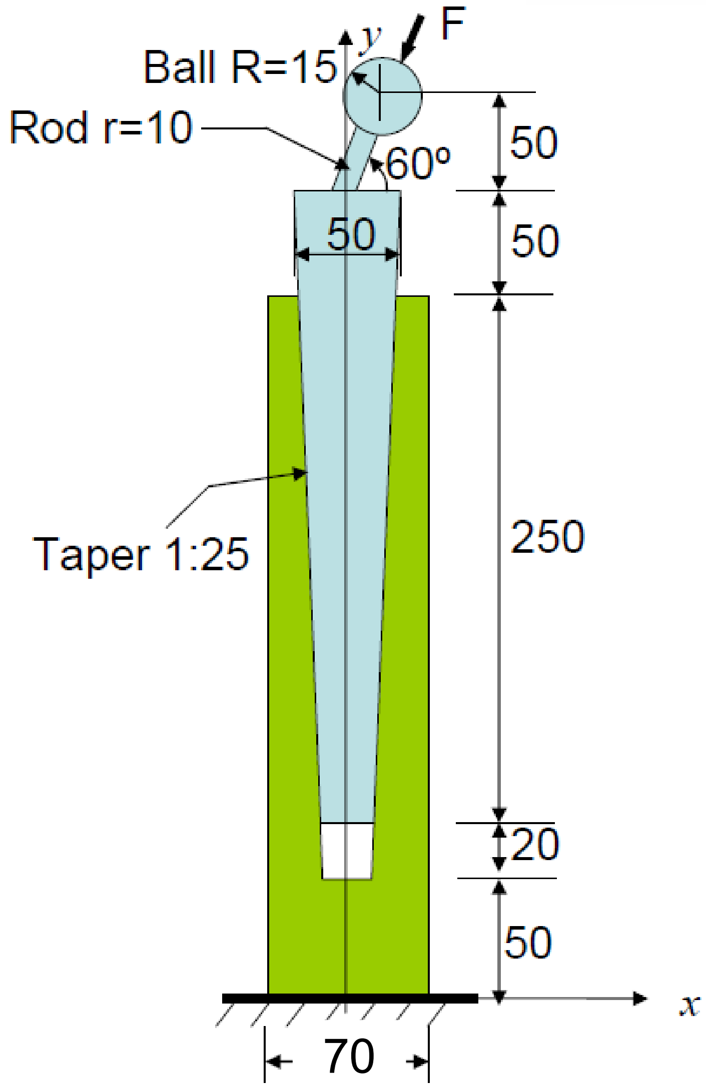
Geometry

In order to simplify the present study, the geometry of the femoral component and of the femur is idealized.

The femur is assumed to be a cylinder with a conical hole. The femurs has a circular shape. We assumed that the femur is only composed with cortical bone.

The geometry of the femoral component (or implant) is presented in the figure. The implant is attached to the femur via a taper similar to a morse taper. The implant is composed with cobalt–chromium alloy.

➔ Note that all the dimensions are in millimeter.



(http://sydney.edu.au/engineering/)

Materials

The implant material is a cobalt–chromium alloy. The behaviour of this material is assumed to be elastic isotropic. A linear elastic model can be used, the Young's modulus and the Poisson's ratio are defined by :

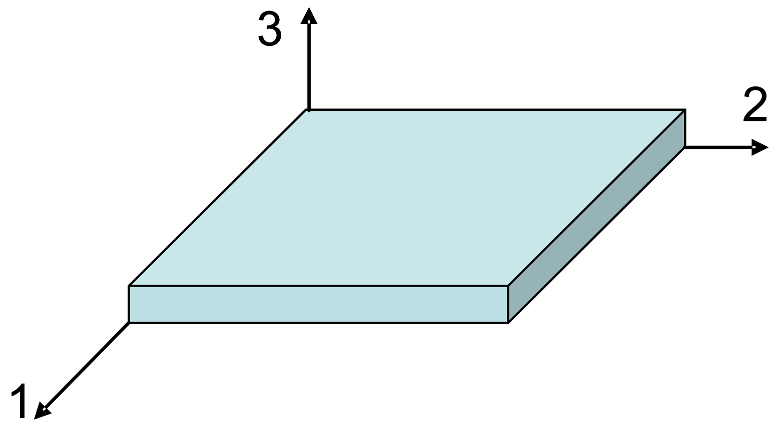
- E = 110 Gpa and ν = 0.316.

The femur is only composed by cortical bone. Cortical bone was considered as transversely isotropic elastic material. The elastic constants are :

- $E_x = E_y$ = 11.5 GPa, E_z = 17 Gpa;
- G_{xy} = 3.6 GPa, $G_{xz} = G_{yz}$ = 3.3 Gpa;
- ν_{xy} = 0.51, $\nu_{xz} = \nu_{yz}$ = 0.31.

➔ The Hook's law for a transverly isotropic elastic material is written as follows :

$$\begin{Bmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \varepsilon_{33} \\ \varepsilon_{23} \\ \varepsilon_{13} \\ \varepsilon_{12} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{12}}{E_1} & -\frac{\nu_{31}}{E_1} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_1} & -\frac{\nu_{31}}{E_1} & 0 & 0 & 0 \\ -\frac{\nu_{31}}{E_3} & -\frac{\nu_{31}}{E_3} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{31}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{2(1+\nu_{12})}{E_1} \end{bmatrix} \begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{33} \\ \sigma_{23} \\ \sigma_{13} \\ \sigma_{12} \end{Bmatrix}$$



Interfacial modelling

In hip-replacement, uncemented implants are selected for patients with good quality bone that can resist the forces needed to drive the implant in tightly. Cemented implants are typically selected for patients with poor quality bone who are at risk of fracture during implant insertion.

In the present study, the cement is not modelled but it is considered via an interface model. Two cases must be considered to model the femur–bone-cement interface :

➔Cemented interface (bonded contact type),

➔Uncemented interface (surface to surface contact type).

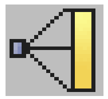
In the case of uncemented interface, the contact between the implant and the bone is described by Coulomb's friction model. The coefficient of friction can be taken equal to $\mu = 0$ (frictionless) or $\mu = 0.2$.

➔Cemented interface (bonded contact type) :

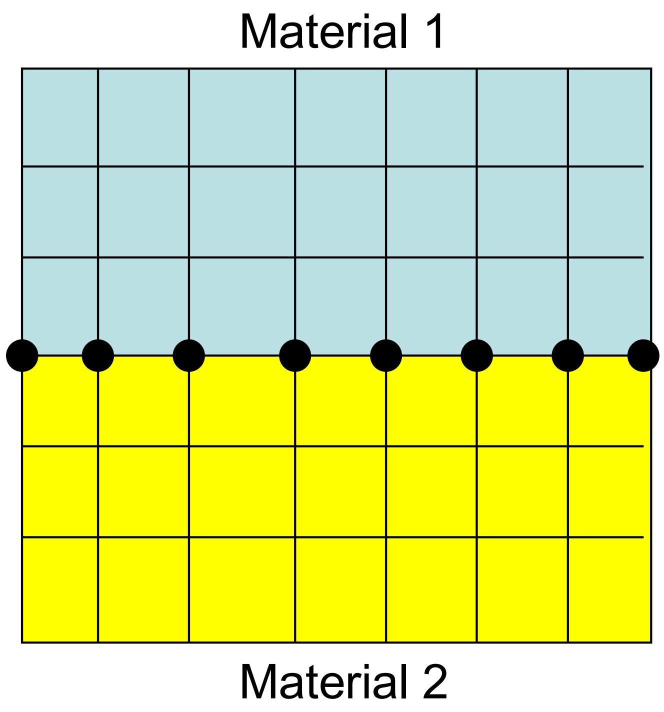
To model the cemented interface use a « tie constraint » in ABAQUS/CAE. A tie constraint ties two separate surfaces together so that there is no relative motion between them. This type of constraint allows you to fuse together two regions even though the meshes created on the surfaces of the regions may be dissimilar. You can define a tie constraint between edges of a wire or between faces of a solid or shell.

ABAQUS/CAE Usage:

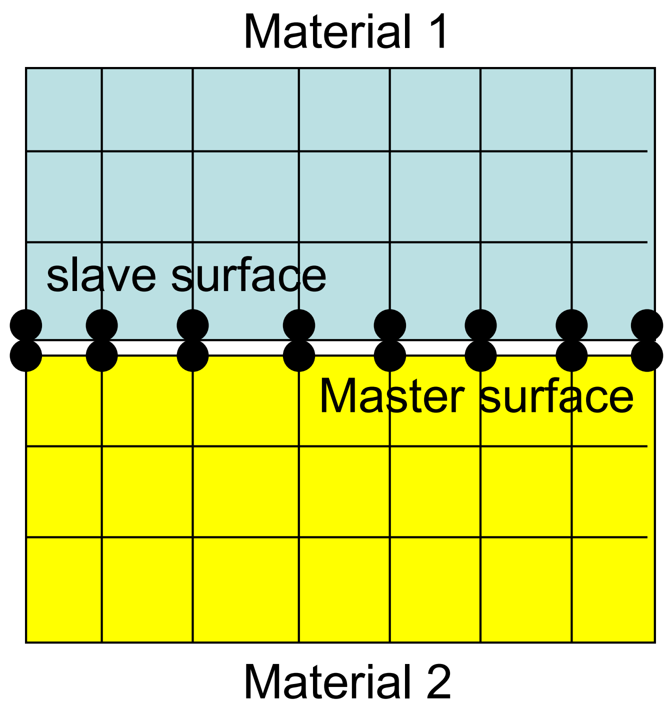
Interaction module: Constraint → Create → From the Type list, select Tie.

Tip : You can also create a tie constraint using the  tool in the Interaction module toolbox.

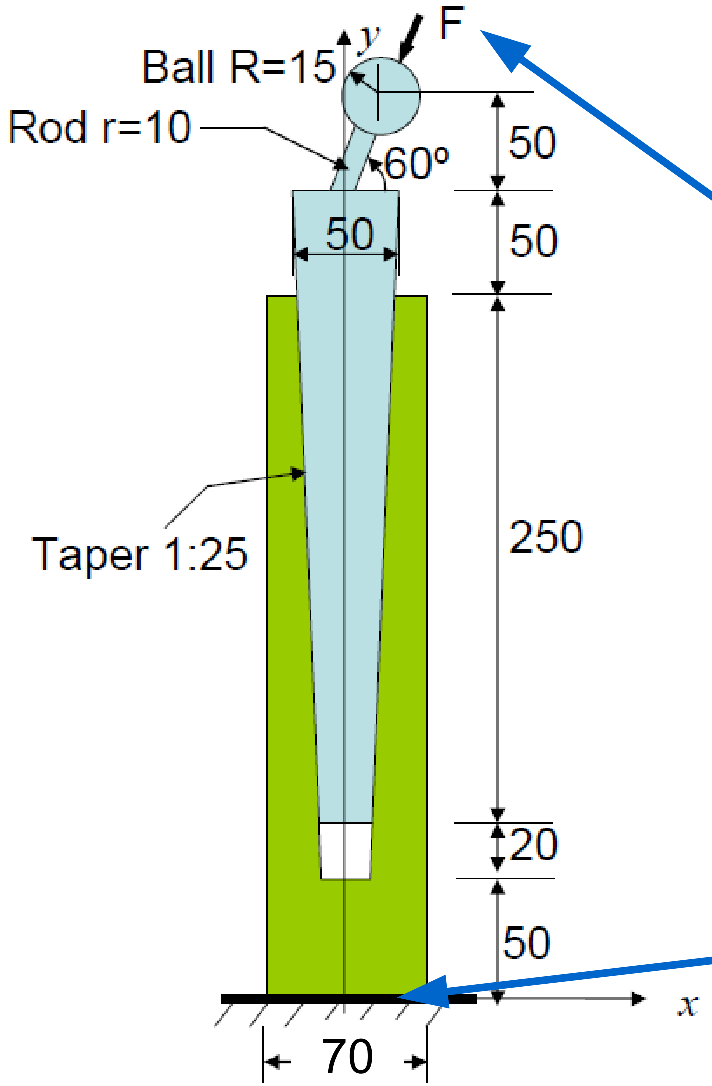
Cemented interface
(Interaction - Tie constraint)



Uncemented interface
(Interaction - Mechanical contact)



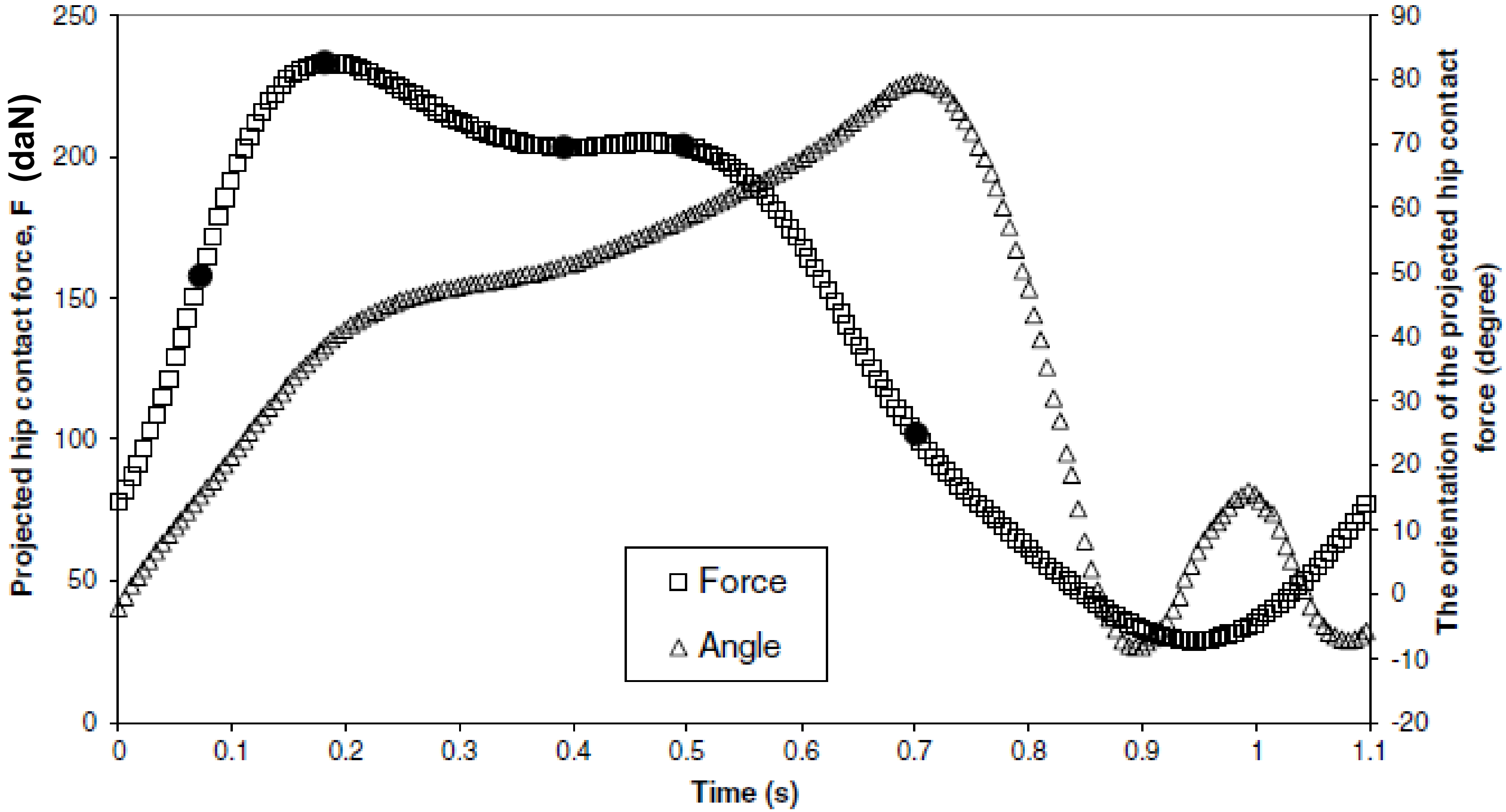
Boundary conditions and loading



The force applied on the ball is called the hip contact force. The components of the hip contact force vary during the walking (during time). The magnitude and direction of the hip contact force during gait is presented in the next slide.

We assume that the lower part of the femur can be fully constrained (no allowed displacement).

(Zant *et al.*, 2007)



A peak hip contact force of 2300 N was assumed acting at an angle of 38.5 degrees from the vertical plane.

TASKS

- ➔ Create FE models with ABAQUS/Standard in 2D or/and in 3D for different load cases (at least 3),
- ➔ Compare the simulations for different element types (linear and quadratic) and conclude,
- ➔ Investigate the effect of material properties on stresses (firstly consider the cortical bone as an isotropic elastic material and then as a transversely elastic material)
- ➔ Investigate stress patterns for cemented and uncemented interfaces,
- ➔ Write a report.

REFERENCES

References

ABAQUS user manuals, Version 6.5, Hibbitt, Karlsson and Sorensen Inc. (2005), Pawtucket, USA.

O. Kayabasi, B. Ekici, The effects of static, dynamic and fatigue behavior on three-dimensional shape optimization of hip prosthesis by finite element method, Materials and Design **28** (2007) pp. 2269–2277.

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Q. Li, AMME4981 – Applied biomedical engineering (2011). (http://sydney.edu.au/engineering/aeromech/people/academic/qingli)