Human Cranium Mechanical Analysis
by Using ANSYS Software

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By the guidance of our supervisor , and by the acceptance of all members in the testing committee , this project is delivered to department of electrical and computer engineering in the college of engineering and technology, to be as a partial fulfillment of the requirement of the department for the degree of B.sc .

Supervisor signature

Testing committee signature

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The head of department signature

جامعة بوليتكنك فلسطين

فلسطين–الخليل

كلية الهندسة

دائرة الهندسة الكهربائية

Human Cranium Dynamic Analysis
By Using ANSYS Software

فريق المشروع:

إيمان أبو طبيخ سماح خلَاف

بناء على نظام كلية الهندسة وإشراف ومتابعة المشرف المباشر على المشروع وموافقة أعضاء اللجنة المناقشة , تم تقديم هذا العمل لدائرة الهندسة الكهربائية

وذلك للوفاء بمتطلبات درجة البكالوريوس في هندسة الأجهزة الطبية.

توقيع المشرف

توقيع اللجنة المناقشة

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توقيع رئيس الدائرة

الإهداء

نحن اليوم نقف أمامكم وها نحن وصلنا وبيدينا شعلة علم وسنحرص كل الحرص عليها حتى لا تنطفئ ونشكر الله أولا وأخير على أن وفقنا وساعدنا على ذلك

ثم نتقدم بالشكر إلى مخرج البشرية جمعاء من الظلمات إلى لنور محمد صلى الله عليه وسلم

إلى القلب الحنون من كانت بجانبنا بكل المراحل التي مضت من تلذذت بالمعاناة وكانت شمعه تحترق لتنير دربنا .. إلى أمهاتنا الحبيبات

وإلى من علمنا أن نقف وكيف نبدأ الألف ميل بخطوة إلى يدنا اليمنى إلى من علمنا الصعود وعيناه تراقبنا .. والدنا

إلى من لهم الفضل بإرشادنا إلى طريق العلم والمعرفة أساتذتنا الأفاضل كم نحن فخورون بكم

أصدقائنا وأحبتنا

إلى من زرعوا التفاؤل في دربنا وقدموا لنا المساعدات والتسهيلات والمعلومات

إلى من هم كالشمعة

فلولا وجودهم لما أحسسنا بمتعة العمل و حلاوة البحث ، و لما وصلنا إلى ما وصلنا إليه فلهم منا كل الشكر

نشكركم بكل ما تحمله كلمة شكر من معنى ونهدي لكم كل عمرنا يا أجمل ما مضى به

نشكركم تنطقها قلوبنا على ألسنتنا .. نشكركم كلمة تعني لنا الكثير وتحمل من الشعور الكثير

تخوننا كل عبارات الشكر في تقديم ما يليق بكم لن ننسى الفضل ولن ننساكم أبدا.

Abstract

Head injuries are one of the main causes of death or permanent invalidity in everyday life. In order to gain a better understanding of head injury mechanisms, it is useful to study the dynamic response of the human-skull as a mechanical system subject to different impact loads.

The main purpose of the present work is to build and validate a numerical model of human head by ANSYS Program in order to evaluate pressure and stress dividends in bones and brain tissues due to impact, Such that the development of a computer model that allows the study of such phenomena requires the knowledge of the anatomy of the human head, the mechanical properties of the tissues involved.

Reverse engineering analysis performed to obtain computer 3D diagram of the skull model. This computer 3D model is then fed into ANSYS software to carry out dynamic analysis and to evaluate the risk of head injury in different impacts, to increase the success rate during skull surgery as much as possible.

ملخص

تعتبر إصابات الرأس من الأسباب الرئيسية للوفاة أو العجز الدائم في الحياة اليومية. من أجل الحصول على فهم أفضل لآليات إصابات الرأس ، من المفيد دراسة الاستجابة الديناميكية لجمجمة الإنسان كنظام ميكانيكي يخضع لتأثير الأحمال المختلفة الغرض الرئيسي من العمل الحالي هو التطوير على نموذج رقمي للجمجمة والتحقق من صحته باستخدام برنامج ANSYS من اجل تقييم الضغط والتوتر في العظام والأنسجة بسبب الاصطدام. حيث إن التطوير على هذا النموذج يتطلب معرفة تشريح الرأس البشري، والخصائص الميكانيكية للأنسجة يتم إجراء التحليل الهندسي العكسي للحصول على رسم تخطيطي ثلاثي الأبعاد للكمبيوتر(3D) لنموذج الجمجمة وبعد ذلك يتم إدخال هذا النموذج ثلاثي الأبعاد في الكمبيوتر باستخدام برنامج ANSYS لإجراء تحليل ديناميكي بعد تأثير قوى مختلفة على الجمجمة لتقييم خطر الإصابة، وذلك يفيد في زيادة معدل النجاح خلال جراحة الجمجمة قدر الإمكان.

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1.1 Thesis Overview

Head injuries due to direct impact are major reasons of death and disability as the result of transportation collisions, falls, assaults, military and sport accidents. In order to gain a better understanding of head injury mechanisms, it is useful to study the dynamic response of the head-brain complex as a mechanical system subject to impact loads.

During many years scientists have been trying to explain pathologies due to cerebral trauma searching for injury mechanisms, psychophysics consequences and possible treatments.

The development of a computer model that allows the study of such phenomena requires the knowledge of the anatomy of the human head, the mechanical properties of the tissues involved, the representation of various forces acting on the tissues and the boundary conditions reflecting a realistic head impact scenario and find basic dynamic characteristic of human cranium such as natural frequencies, damping ratios, mode shapes, etc. and to increase the success rate during skull surgery. Reverse engineering is performed to obtain computer 3D diagram of the skull model. This computer 3D model is then fed into ANSYS FEM (Finite Element Method) software to carry out dynamic analysis and to evaluate the risk of head injury in different impacts.

1.2 Main Objective

1) To build and validate a numerical model of human head in order to evaluate pressure and stress distributions in head due to different impacts.
2) To build up and analysis geometric 3D skull into ANSYS Finite element analysis (FEA package).

1.3 Project Importance:

1) Turned doctors attention to identify the status of the wounded instead of focusing on the injured party of the patient. Moreover, play role in finding solution for the problems that might affect the body organs.
2) To reduce the risk as much as possible by fully understanding the dynamic characteristic of human cranium for selecting the best surgery method, position, and cutting parameter of the skull.
3) Demonstrate that biomedical engineering is not only interested in devices but also interested in the human body and its members.

1.4 Block Diagram

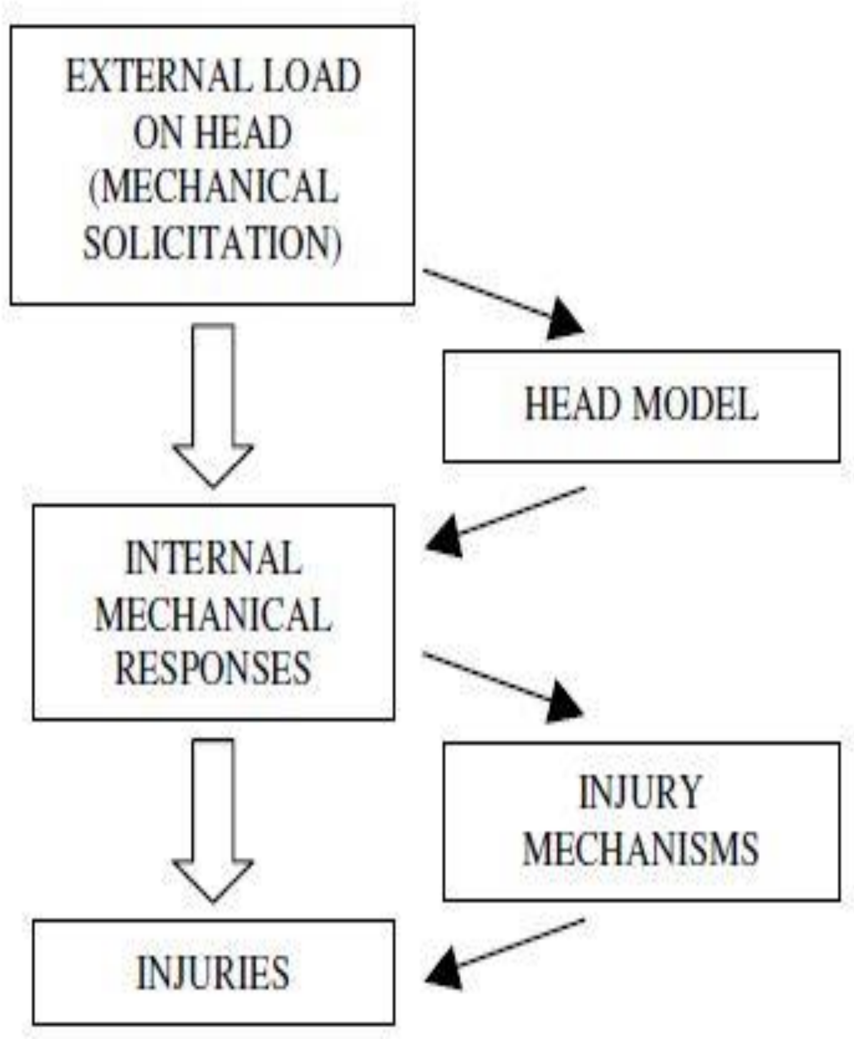


Figure 1.1: Block Diagram For Human Cranium Analysis

Head models can be used to study the possibility of injury due to an external load (See figure1.1). Effective way to predict several different head injuries (skull fracture, contusions, hemorrhage, diffuse axonal injury ...) is the implementation and application of a finite element human head models.

1.5 Materials & Methods

Reverse engineering (RE) is performed to obtain computer 3D diagram of the skull model. This computer 3D model is then fed into ANSYS FEM software to carry out dynamic analysis and to evaluate the risk of head injury in different impacts.

1.6 Literature Review and Related Work

"Finite Element Modeling Of The Human Brain Under Impact Condition".

The head is the most vulnerable part of the body during crash situations and is often involved in life-threatening injuries. The main purpose of the present work is to build and validate a numerical model of human head in order to evaluate pressure and stress distributions in bones and brain tissues due to impact. Furthermore, the Head Injury Criterion (HIC) and the recently proposed Head Impact Power (HIP) criterion were evaluated with respect to the relative motion between the skull and the brain. It was found that the influence of impact direction had a substantial effect on the intracranial response. Geometrical characteristics for the finite element model have been extracted from CT and MRI scanner images, while material mechanical characteristics have been taken from literature. The analysis is performed using the program ANSYS 3D to evaluate the risk of head injury in impact. The model is validated by comparing the numerical results and the experimental results obtained by Nahum in 1977 [1].

"Dynamic Response Of The Human Head to Impact By Three-Dimensional Finite Element Analysis"

The impact response of the human head has been determined by three-dimensional finite element modeling. This model represents the essential features of a 50th percentile human head. It includes a layered shell closely representing the cranial bones with the interior contents occupied by an inviscid continuum to simulate the brain. A thin fluid layer was included to represent the cerebral-spinal fluid. To validate the model, its response was obtained by applying a sine-squared pulse of 6.8 kN in magnitude and 10 ms in duration. The load was applied to a freely supported head on the frontal bone in the mid sagittal plane. The computed pressure-time histories at 5 locations within the brain material compared quite favorably with previously published experimental data from cadaver experiments and provided a reasonable level of confidence in the validation of the model. A parametric study was subsequently conducted to identify the model response when the impact site (frontal, side, occipital) and the material properties of the head were varied. Interestingly, the model predicted higher contra-coup pressure in the frontal lobe (from occipital impact) than that predicted in the occipital region from frontal impact. This finding supports clinical findings of contra-coup injury being more likely to result from occipital impact than from frontal impact [2].

″Human Cranium Dynamic Analysis ″

The head is the most vulnerable part of the body during crash situations and is often involved in life-threatening injuries. The main purpose of the present work is to build and validate a numerical model of human head in order to evaluate pressure and stress distributions in bones and brain tissues due to impact. Furthermore, the Head Injury Criterion (HIC) and the recently proposed Head Impact Power (HIP) criterion were evaluated with respect to the relative motion between the skull and the brain. It was found that the influence of impact direction had a substantial effect on the intracranial response. Geometrical characteristics for the finite element model have been extracted from CT and MRI scanner images, while material mechanical characteristics have been taken from literature. The analysis is performed using the program ANSYS 3D to evaluate the risk of head injury in impact. The model is validated by comparing the numerical results and the experimental results obtained by Nahum in 1977[3] .

“Measure head Impact contact pressure effect in collegiate Football games to Correlate the head of Kinematics to the brain Kinetics Elucidating brain injury Dynamics”

Does a brain store thoughts and memories the way a computer saves its files? How can a single hit or a fall erase all those memories? Brain Mapping and traumatic brain injuries (TBIs) have become widely researched fields today. Many researchers have been studying TBIs caused to adult American football players however youth athletes have been rarely considered for these studies, contradicting to the fact that American football enrolls highest number of collegiate and high-school children than adults. This research is an attempt to contribute to the field of youth TBIs.

Earlier studies have related head kinematics (linear and angular accelerations) to TBIs. However, fewer studies have dealt with brain kinetics (impact pressures and stresses) occurring during head-on collisions. The National Operating Committee on Standards for Athletic

Equipment (NOCSAE) drop tests were conducted for linear impact accelerations and the Head Impact Contact Pressures (HICP) calculated from them were applied to a validated FE model. The results showed lateral region of the head as the most vulnerable region to damage from any drop height or impact distance followed by posterior region.

The TBI tolerance levels in terms of Von-Mises and Maximum Principal Stresses deduced for lateral impact were 30 MPa and 18 MPa respectively. These levels were corresponding to 2.625 feet drop height. The drop heights beyond this value will result in TBI causing stress concentrations in human head without any detectable structural damage to the brain tissue. This data can be utilized for designing helmets that provide cushioning to brain along with providing a resistance to shear [4].

1.7 Schedule Time

we make a plan for the predictive project tasks due to the time of this semesters, this time plan shown in the table.

Table 1-1: Timing Schedule of the First semester

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project selection															
Collecting from different information															
Introduction Chapter 1															
Chapter 2															
Chapter 3															
Chapter 4															
Chapter 5															

Table1.2: Timing Schedule of the Second Semester

Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Model drawing and analysis															
Modify the model															
Modify the analysis															
Results															
Analysis the results															
Write the documentation															

Chapter Two

Anatomy Of The Human Head and Injuries

The human head consists of a fleshy outer portion surrounding the bony skull, within which sits the brain. The head rests on the neck, and is provided bony support for movement by the seven cervical vertebrae.

The face is the anterior part of the head, containing the sensory organs the eyes, nose and mouth. The cheeks, on either side of the mouth, provide a fleshy border to the oral cavity To either side of the head sit the ears. It is important to know the interactions between the brain and skull as well as the interior components of the brain when discussing brain injury.

2.1 The Skull

The skull is the main protective barrier for the brain. It is composed of both cranial and facial bones, with the cranial bones forming the protective shell around the brain (Figure2.1).

The human skull is generally considered to consist of twenty-two bones—eight cranial bones and fourteen facial skeleton bones. The eight bones that make up the cranium also provide attachment sites for jaw, head and neck muscles. The cranial cavity, the largest cavity in the skull, has an adult volume of approximately 1300 to 1500 cubic centimeters. The cranial bones are held together by immovable joints called sutures which disappear over time as the adjacent bones fuse together, the size of the skull, specifically the cranial cavity, determines the size of the brain [6].

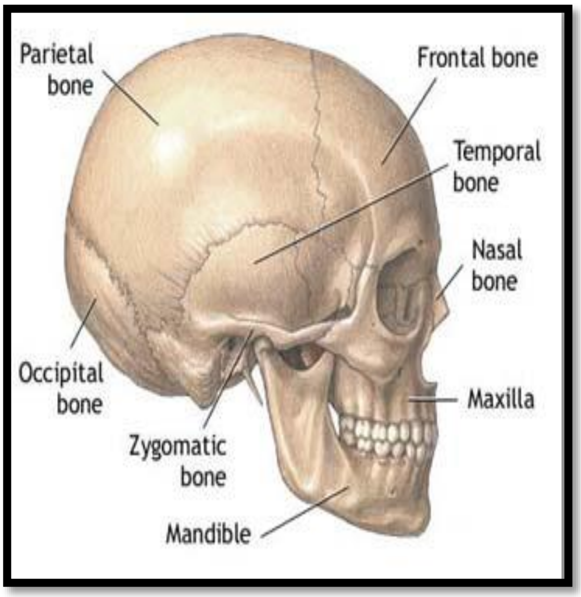


Figure2.1: Skull Anatomy

The skull is comprised of an inner and outer cortical bone layer with a thin cancellous bone layer sandwiched between them. The cortical bone is compact and extremely dense while the cancellous bone is very porous. Cortical bone can withstand greater stress, has a high stiffness, and fractures and very low strains very high strains. The thickness of the spongy core increases toward the center of the bone away from the cranial sutures [8].

Bone is comprised of 60-70% minerals and collagen and exhibits a viscoelastic response to loading. This type of response results in variable stress-strain properties that are dependent on the strain rate. The mechanical properties of the cranial bones have been found through 26 experimental tests on human cadavers (Table2.1). It is important to note the anisotropic behavior of the cortical bone material. For the purposes of the experimental study orientation angles were taken with respect to the sagittal suture with 0° corresponding to a vector tangential to the suture and 90° corresponding to a vector normal to the suture. The first two values are for specimens taken from the frontal bone while the last two values are for specimens taken from the parietal bone Figure2.1.b.

The skull is one of the least deformable structures found in nature. It needs the force of about 1 ton to reduce the diameter of the skull by 1 cm[15].

Table 2.1: Mechanical properties of cranial bone

Mechanical Properties of Cranial Bone Orientation	K [MPa]	G [MPa]	E [MPa]	σy [MPa]
0°	16900	11660	28300	98.0
45°	11700	8073	19656	80.0
90°	14460	9954	24000	92.0
45°	5080	3450	9740	58.4

- **K**: shear correction factor
- **shear modulus (G)**: The shear modulus is concerned with the deformation of a solid when it experiences a force parallel to one of its surfaces while its opposite face experiences an opposing force .
- **Elastic modulus (E)**: is a number that measures an object or substance's resistance to being deformed elastically
- **σ :** is stress [MPa]

2.2 The Brain

1) Cranium is the first line defense of Brain.
2) Meninges, a three layers covering, beneath the Cranium. [the three layers are - Dura mater, arachnoid and pia mater].
3) Cerebrospinal Fluid (CSF): part from solid protection of Cranium and Meninges, the brain is cushioned by being surrounded by and filled with a watery fluid known as CSF.

The human brain is the largest and most complex part of the nervous system with a volume ranging from 1200 to 1500 cubic centimeters and an average weight of 1.35 to 1.4 kilograms. It is composed of about one hundred billion neurons and innumerable nerve fibers (Figure 2).

It controls all functions in the human body including sensory systems, movement, behavior, emotion, memory and learning. These commands are carried out by neurons which are the functional unit of the nervous system that are specialized for rapid communication. A neuron is composed of a cell body, dendrites and an axon which carries impulses away from the cell body[6].

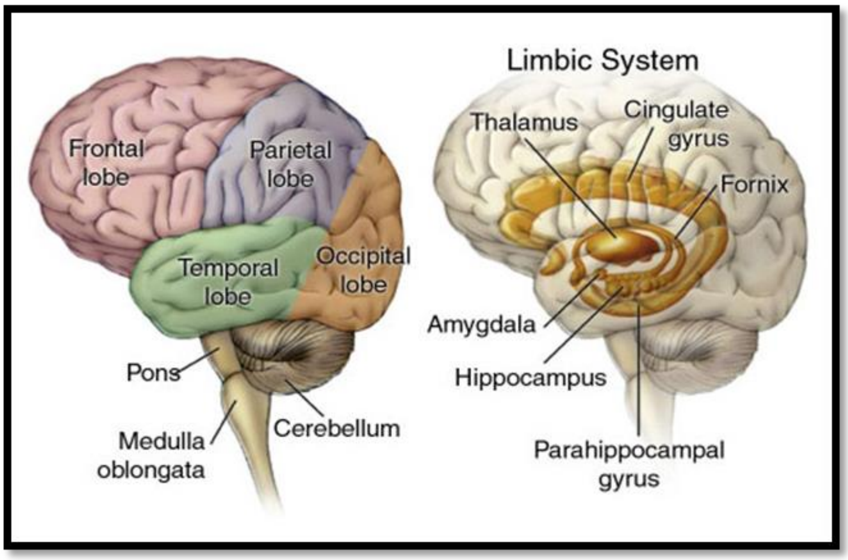


Figure 2.2: Brain anatomy [10].

The cerebrum can be further divided into two parts; the cerebral cortex and the white matter. The cerebral cortex, or grey matter, covers the surface of the brain. It is a superficial layer of grey matter formed by migrating peripheral neurons and is 2 to 5 millimeters in thickness [11]. The white matter lies beneath the grey matter and is composed primarily of myelinated axons [6] and is the area commonly damaged in cases of diffuse axonal injury [12].

2.2.1 Protective Layer Of The Brain

The brain floats within the skull suspended in Cerebra Spinal Fluid (CSF) and is protected by many layers (Figure 3) including the skull. The surface of the brain consists of folds, grooves, and fissures which subdivide the brain into hemispheres and smaller areas [13].

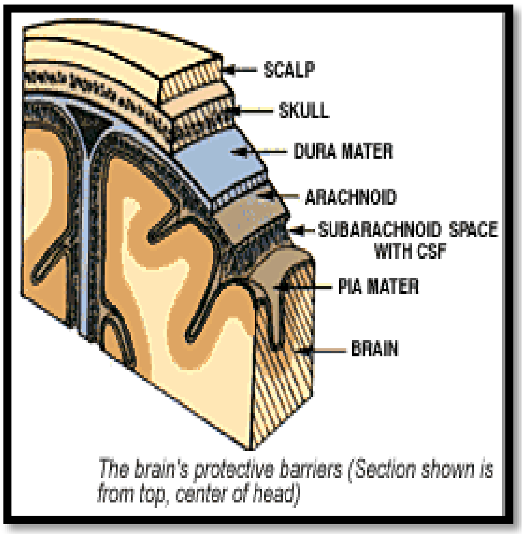


Figure2.3: Layers protecting the brain

The Dura Mater is a connective tissue composed of two fibrous layers and is the strongest of the three connective tissue layers (cranial meninges). The Arachnoid is composed of a web of collagen and elastic fibers.

Cerebrospinal fluid (CSF) is a clear, colorless liquid that bathes the exposed surfaces of the central nervous system, completely surrounding the brain and spinal cord. The CSF supports the brain (95% of its weight) and prevents it from being crushed under its own weight. CSF is a Newtonian fluid with a dynamic viscosity (μ) and density (ρ) similar to plasma ($\mu = 0.01$ and $\rho = 1.0$ g/cm3) [16]. The CSF is secreted and reabsorbed continuously resulting in a relatively constant fluid pressure of about 10 mm Hg (1333 Pa) [11].

To help understand the procedures carried out during this project a brief introduction to the field of head injuries is given in this section. Importance of studying traumatic of head injuries, its causes and effects on the quality of life are presented.

2.3 Head injury

A head injury is any sort of injury to brain, skull, or scalp. This can range from a mild bump or bruise to a traumatic brain injury. Common head injuries include concussions, skull fractures, and scalp wounds. The consequences and treatments vary greatly, depending on what caused the head injury and how severe it is.

Head injuries may be either closed or open. A closed head injury is any injury that doesn't break skull. An open, or penetrating, head injury is one in which something breaks your skull and enters brain. It can be hard to assess how serious a head injury is just by looking. Some minor head injuries bleed a lot, while some major injuries don't bleed at all. It's important to treat all head injuries[32].

2.3.1 Causes Of a Head Injury

In general, head injuries can be divided into two categories based on what causes them. They can either be head injuries due to blows to the head or head injuries due to shaking.

Head injuries caused by a blow to the head are usually associated with:

- motor vehicle accidents .
- falls .
- physical assaults.
- sports-related accident

2.3.2 Head Injury Mechanism

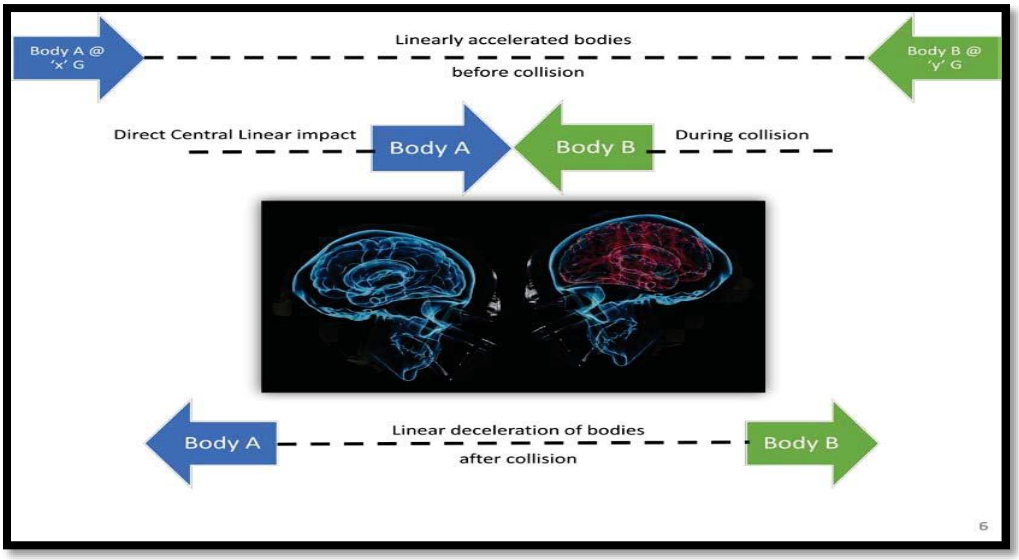


Figure 2.4: Pictorial representation of head-on collision to explain head injury mechanism

Referring to Figure2.4, consider two body running towards each other at different linear acceleration. Assuming that the impact is direct central linear impact i.e. both the bodies are hitting each other in a straight line then the transmission of energies from one body to other will occur. The two bodies will experience a reactive impact force pushing them in opposite directions and decelerating them[33].

2.4 Frontal bone

The frontal bone is classified as a flat bone due to its relatively thin and flat shape. Like all flat bones, the frontal bone has spongy bone in its center, surrounded by a thin layer of compact bone on its inner and outer surfaces[34].

The primary functions of the frontal bone are the protection of the brain and the support of the structures of the head. Although the frontal bone follows the ridges of the brain very closely, a small gap between the frontal bone and brain houses the meninges and the cerebrospinal fluid of the cranium.

2.4.1 Frontal lobe injury

The frontal lobe of the human brain is relatively large in mass, It is a component of the cerebral system, which supports goal directed behavior [35]. This lobe is often cited as the part of the brain responsible for the ability to decide between good and bad choices, as well as recognize the consequences of different actions. Because of its location in the anterior part of the head, the frontal lobe is arguably more susceptible to injuries[36].

Figure 2.5: cross-section of a human brain. The portion in color is the left frontal lobe

2.4.2 Coup Contrecoup injury

In head injury, a coup injury occurs under the site of impact with an object, and a contrecoup injury occurs on the side opposite the area that was hit[37]. Coup and contrecoup injuries are associated with cerebral contusions; a form of traumatic brain injury, it is a bruise[38].

Coup and contrecoup injuries are considered focal brain injuries, A focal traumatic injury results from direct mechanical forces (such as occur when the head strikes a windshield in a vehicle accident) and is usually associated with brain tissue damage visible to the naked eye[39].

During an impact the brain undergoes linear acceleration and deceleration forces or rotational forces, causing it to collide with the opposite side of the skull[40].

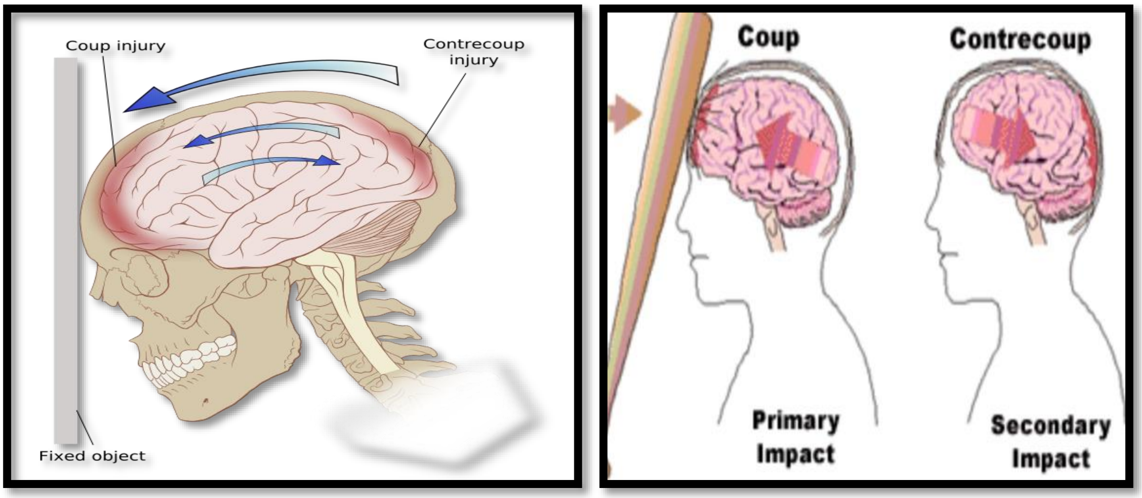


Figure 2.6: Coup Contrecoup injury

2.5 The Major Effects Of Frontal Lobe Injuries

2.5.1 Hematoma

A hematoma is a collection, or clotting of blood outside the blood vessels. It can be very serious if a hematoma occurs in the brain. The clotting can cause pressure to build inside your skull, which can cause you to lose consciousness or result in permanent brain damage[32].

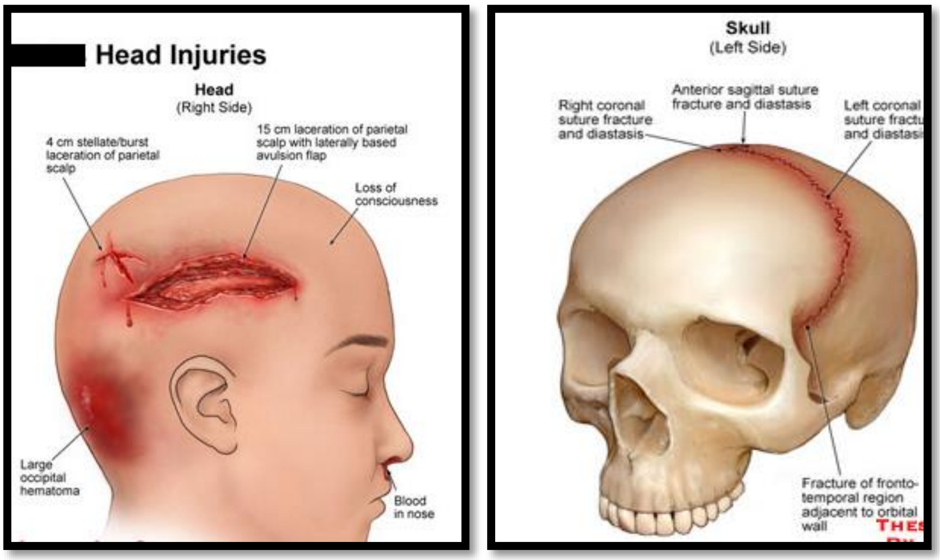


Figure 2.7: Hematoma

2.5.2 Hemorrhage

A hemorrhage is uncontrolled bleeding. There can be bleeding in the space around your brain, which is a subarachnoid hemorrhage, or bleeding within your brain tissue, which is an intra-cerebral hemorrhage. Subarachnoid bleeds often cause headaches and vomiting. The severity of intra-cerebral hemorrhages depends on how much bleeding there is, but over time any amount of blood can cause pressure to build.

2.5.3 Concussion

A concussion is a brain injury that occurs when the brain bounces against the hard walls of the skull. Generally speaking, the loss of function associated with concussions is temporary. However, repeated concussions can eventually lead to permanent damage.

Subarachnoid bleeds often cause headaches and vomiting. The severity of intra-cerebral hemorrhages depends on how much bleeding there is, but over time any amount of blood can cause pressure to build.

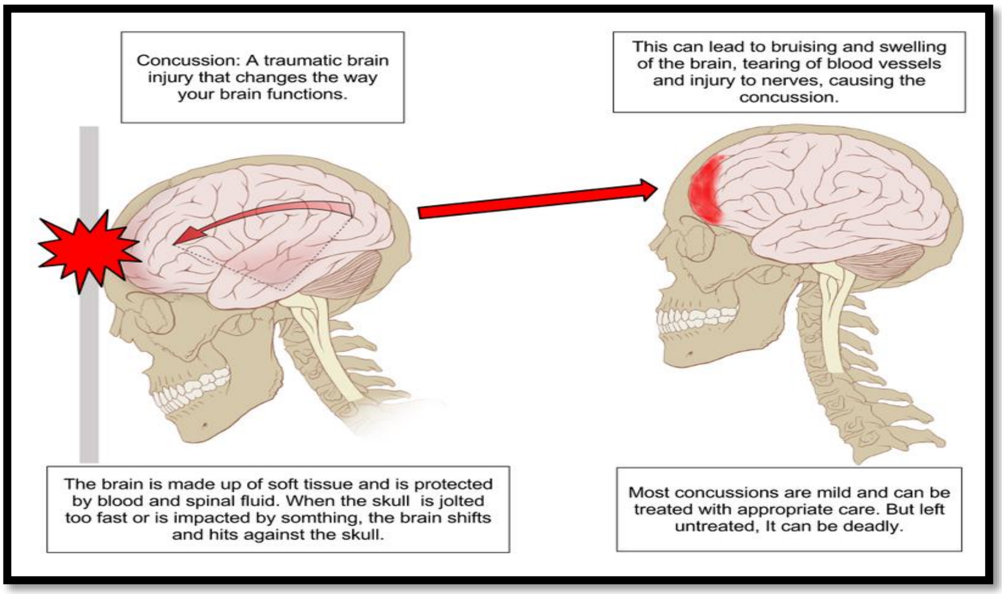


Figure 2.8: concussions

2.5.4 Edema

Any brain injury can lead to edema, or swelling. Many injuries cause swelling of the surrounding tissues, but it's more serious when it occurs in your brain. Your skull can't stretch to accommodate the swelling, which leads to a buildup of pressure in your brain. This can cause the brain to press against of the skull.

2.5.5 Skull fracture

Unlike most bones in the body, the skull doesn't have bone marrow. This makes the skull very strong and difficult to break. A broken skull is unable to absorb the impact of a blow, making it more likely that there will also be damage to the brain.

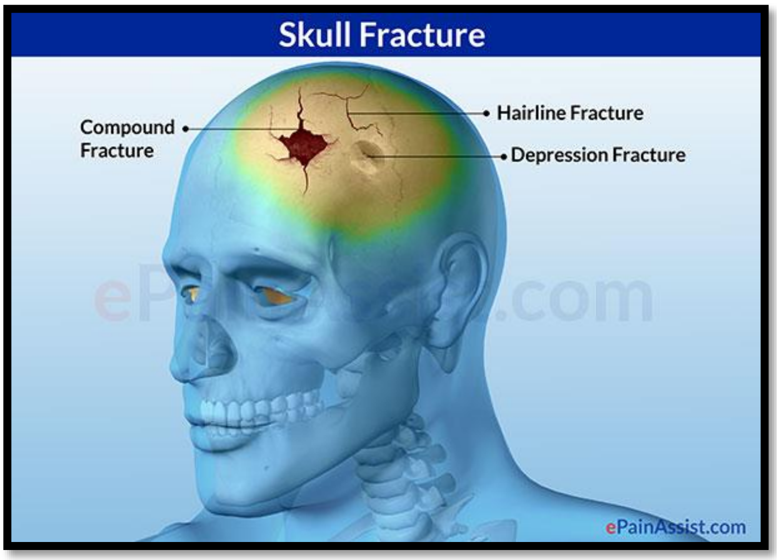


Figure 2.9: Skull fracture

2.5.6 Diffuse axonal injury

A diffuse axonal injury, or sheer injury, is an injury to the brain that doesn't cause bleeding but does damage your brain cells. The damage to the brain cells results in them not being able to function and can also result in swelling, causing more damage. Though it isn't as outwardly visible as other forms of brain injury, diffuse axonal injury is one of the most dangerous types of head injuries and can lead to permanent brain damage and even death.

Chapter Three

Finite Element Method and Reverse Engineering

3.1 FEM

3.1.1 The Basic Steps of the Finite Element Method

3.1.2 The Purpose of FE

3.1.3 Common FEA Application

3.1.4 Discretization

3.1.5 Types of FEM

3.1.6 Advantages of the FEM over other numerical methods

3.2 Reverse Engineering

3.2.1 Elements in Reverse Engineering

3.2.2 Reverse Engineering purpose

3.1 Finite Element Method(FEM)

The finite element method (FEM) is a powerful technique for finding the approximate solution of a partial differential equation (PDE) . In the finite element method, a complex domain is discretized into a number of reasonably elements, such that a set of basic functions can be defined on the elements to approximate the solution [17]. The finite element method converts the elliptic partial differential equation into a set of algebraic equations which are easy to solve. The initial value problems which consist of a parabolic or hyperbolic differential equation.

3.1.1 The Basic Steps of the Finite Element Method:

The solving steps for the strains of cranial cavity are shown in figure3.1**.** The specific numerical solution process is [18].

1) Identifying the discretized cranial cavity.
2) Selecting the displacement mode.
3) Analyzing the mechanical properties of elements and deriving the element stiffness matrix.
4) Collecting all relationship between force and displacement and establishing the relationship between force and displacement of cranial cavity.
5) Solving the nodal displacement.
6) Classifying the nodal displacement and the strain and stress in each element then calculating.

3.1.2 The Purpose of FEA

Design geometry is a lot more complex; and the accuracy requirement is a lot higher. We need:

1) To understand the physical behaviors of a complex object (strength, heat transfer capability, fluid flow, etc…).
2) To predict the performance and behavior of the design; to calculate the safety margin; and to identify the weakness of the design accurately.
3) To identify the optimal design with confidence.

3.1.3 Common FEM Applications :

- Mechanical/Aerospace/Civil/Automotive Engineering
- Structural/Stress Analysis
  1. Static/Dynamic
  2. Linear/Nonlinear
- Fluid Flow
- Heat Transfer
- Electromagnetic Fields
- Soil Mechanics
- Acoustics
- Biomechanics

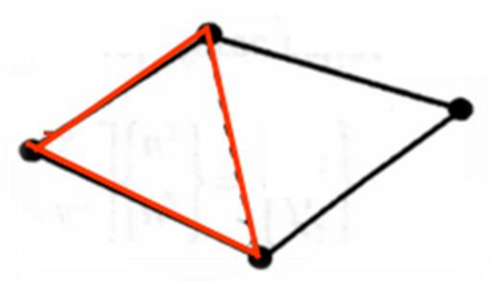
3.1.4 Discretization

Model body by dividing it into an equivalent system of many smaller bodies or units (finite elements) interconnected at points common to two or more elements (nodes or nodal points) and/or boundary lines and/or surfaces [20].

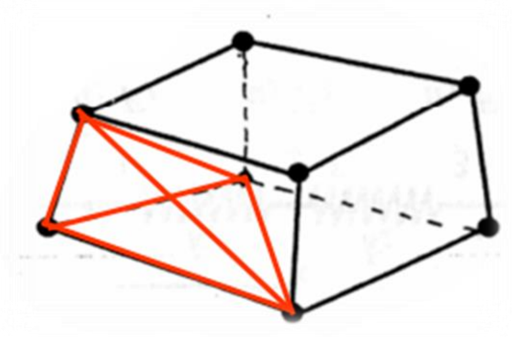
3.1.5 Type of FEM:

1) Line element:

2) Plane element:



3) Solid element:



3.1.6 Advantages of the finite element method over other numerical methods are as follows:

- The method can be used for any irregular-shaped domain and all types of boundary conditions.
- Domains consisting of more than one material can be easily analyzed.
- Accuracy of the solution can be improved either by proper refinement of the mesh or by choosing approximation of higher degree polynomials.
- The algebraic equations can be easily generated and solved on a computer. In fact, a general purpose code can be developed for the analysis of a large class of problems[19].

3.2 Reverse Engineering

Reverse engineering, also called back engineering, is the process of where a man-made object is deconstructed to reveal its designs, architecture, or to extract knowledge from the object[21]. The reverse engineering process in itself is not concerned with creating a copy or changing the artifact in some way; it is only an analysis in order to deduce design features from products with little or no additional knowledge about the procedures involved in their original production[22].

There are various reasons for performing reverse engineering in various fields. For software, reverse engineering can help to improve the understanding of the underlying source code for the maintenance and the improvement of the software. Relevant information can be extracted to make a decision for software development, graphical representations of the code can help to generate alternate views regarding a source code, and to detect and fix a software bug or software vulnerability. Besides, as a software develops over time, information of the software designs and improvements are often lost with time. With reverse engineering, such pieces of lost information can be recovered. Reverse engineering can help to cut down the time required to understand the source code, thus reducing the overall cost of the software production[22].

3.2.1 There are two elements in reverse engineering:

Re-documentation and **Restoration** of design.

Re-documentation is to create a new representation of the computer code so that it is easy to understand. At the same time, design **Restoration** is to use the conclusion or inference of the general knowledge or personal experience of the product in order to fully understand the product functions[22].

It can also be considered as "going back during the development cycle" [23]. In this model, the output of the implementation phase (in source code format) is reversed back to the analysis phase, in contrast to the traditional waterfall model.

3.2.2 Reverse engineering purpose

The main purpose of reverse engineering in manufacturing is repeating the original objects, which exploit whether in the modifying after the initial design stage or in maintenance process (as a spare parts), this process has found use in computer aid designs and animation. Identifies the results of a reverse engineering operation as producing a type three drawing set and a set of intelligent CAD models of the components. Further, they define the reverse engineering preprocess as: [24]

1) Collecting all available information and documentations, including nonproprietary drawings, functional requirements, tooling requirements, processing and material requirements, etc.
2) Identifying new data elements required for a complete technical data package.
3) Performing a cost/benefit analysis.
4) Contacting the cognizant engineer.
5) Establishing a reverse engineering management plan.
6) Establishing acceptance criteria

Chapter Four

Impact Force

4.1 Impact Force

4.2 Impulse and Momentum

4.2.1 Momentum

4.3 Collisions

4.4.1 Before Impact
4.4.2 Maximum Deformation
4.4.3 After Impact

4.4 Linear impact and linear momentum

4.4.1 The Linear Impulse- Momentum Principle

4.5 The Stress and Strain

4.5.1 Brittle and ductile materials

4.6 Deformation

4.8 Finite Element Simulations with Impact Pressures

4.1 Impact Force

An impact is a high force or shock applied over a short time period when two or more bodies collide. Such a force or acceleration usually has a greater effect than a lower force applied over a proportionally longer period. The effect depends on the relative velocity of the bodies to one another.

At normal speeds, during a perfectly inelastic collision, an object struck by a projectile will deform, and this deformation will absorb most or all of the force of the collision. The way in which the kinetic energy is distributed through the section is also important in determining its response [25].

4.2 Impulse and Momentum

All particles with mass experience the effects of impulse and momentum. Momentum and inertia are similar concepts that describe an objects motion, however inertia describes an objects resistance to change in its velocity, and momentum refers to the magnitude and direction of it's motion. Momentum is an important parameter to consider in many situations such as braking in a car or playing a game of billiards. An object can experience both linear momentum and angular momentum. The nature of linear momentum will be explored in this module.

4.2.1 Momentum

Anybody that is in motion has momentum. A force acting on a body will change its momentum. The momentum of a particle is defined as the product of the mass multiplied by the velocity of the motion. Let the variable represent momentum:

$$\mathbf{L= m \cdot v} \tag{4.1}$$

Recall Newton's second law of motion.

$$\mathbf{F= m.a} \tag{4.2}$$

This can be rewritten with acceleration as the derivate of velocity with respect to time.

$$\mathbf{F=m.} \frac{d}{dt} v \tag{4.3}$$

If this is integrated from time t_1 to t_2

$$\int_{t1}^{t2} \boldsymbol{F}\, \boldsymbol{dt} = \mathbf{m.v_2 - m.v_2} \qquad (4.4)$$

Moving the initial momentum to the other side of the equation yields

$$\mathbf{m.v_1} + \int_{t1}^{t2} \boldsymbol{F}\, \boldsymbol{dt} = \mathbf{m.v_2} \qquad (4.5)$$

the integral in the equation is the impulse of the system; it is the force acting on the mass over a period of time t1 to t2can be rewritten as the sum of the momentum and impulses.

$$\sum \mathbf{m.v_1} + \sum \mathbf{F.\Delta t} = \sum \mathbf{m.v_2} \qquad (4.6)$$

4.3 Collisions

Collision is short-duration interaction between two bodies or more than two bodies simultaneously causing change in motion of bodies involved due to internal forces acted between them during this.

When two particles collide and there are no external impulsive forces acting on them, total momentum is conserved. The equation becomes

$$\sum \mathbf{m.v_2} = \sum \mathbf{m.\ v_1} \qquad (4.7)$$

If two particles of mass m_a and m_b collide, their resulting velocities will change. The motion of these particles can be expressed by V_0 andV_1 before and after the collision, respectively, in the following equation.

$$\mathbf{m_a v_{a0} + m_b v_{b0} = m_a v_{a1} + m_b v_{b1}} \qquad (4.8)$$

4.3.1 Before Impact

Let particle 1 of mass m1, occupy position X1 and travel with velocity V1 along the direction parallel to the line joining the two particles. And let particle 2 of mass m2, occupy position X2 and travel with speed V2 also in the same direction. We assume that V1 > V2 so that collision will occur[28].

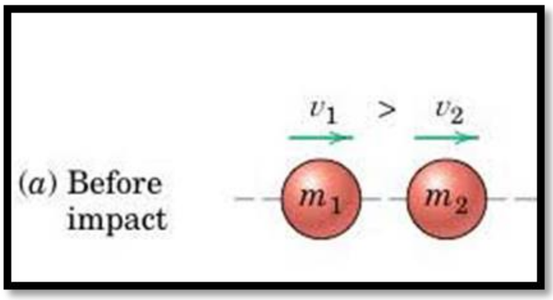


Figure4.1 : Particles befor impact

4.3.2 Maximum Deformation

The contact force is at its maximum and the two particles travel at the same velocity V0. Thus the deformation force has slowed m1 down to a velocity of V0 and sped up m2 to a velocity of V0. The impulse applied to particle 1 and 2 from the deformation force equals the change in momentum in the deformation process[28].

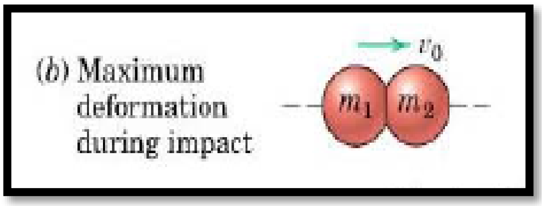


Figure4.2 : Particles during impact

4.3.3 After Impact

The particles travel with a constant velocity V1 and V2 .[28]

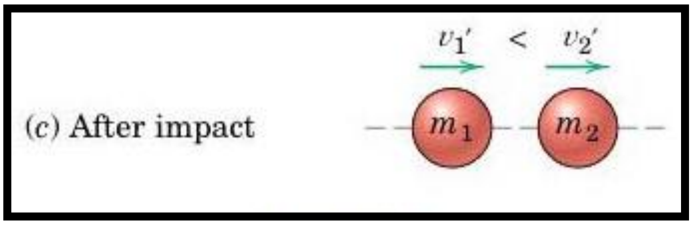


Figure4.3 : Particles after impact

4.5 Linear impact and linear momentum

Consider the general curvilinear motion in space of particle of mass m, figure4.5 where the particle is located by its position vector r measured from a fixed origin O. The velocity of the particle is v= r and is tangent to its path. The resultant ∑F of all forces on m is in the direction of its acceleration v. We may write the basic equation of motion for the particle as:

$$\sum \mathbf{F} - \mathbf{mv} - \frac{d(mv)}{dt} = \sum \mathbf{F} = \mathbf{G} \qquad (4.11)$$

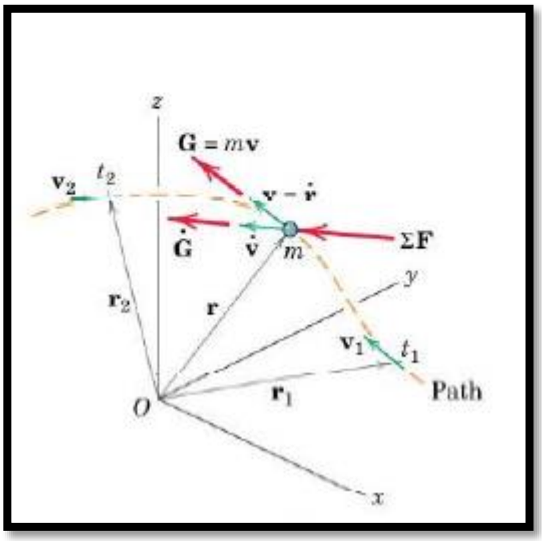


Figure 4.4: curvilinear motion

Where the product of the mass and velocity is defined as linear momentum of the particle. The unit of linear momentum mv is (Kg.m/s).

4.4.1 The Linear Impulse- Momentum Principle:

Now we able to describe the effect of the resultant force ∑F on the linear momentum of the particle. The product of force and time is defined as the *linear impulse* of the force.

$$\mathbf{G_1} + \int_{t1}^{t2} \sum \boldsymbol{F} \boldsymbol{dt} = \mathbf{G_2} \qquad (4.12)$$

Which says that the initial linear momentum of the body plus the linear impulse applied to it equals its final linear momentum.

The impulse integral is a vector which, in general, may involve changes in both magnitude and direction during the time interval. Under these conditions, it will be necessary to express $\sum F$ and G in component form and then combine the integrated components. The components of Eq.4.12 are the scalar equations.

4.5 Stress and Strain

The stress applied to a material is the force per unit area applied to the material. The maximum stress a material can stand before it breaks is called the breaking stress or ultimate tensile stress.

Tensile means the material is under tension. The forces acting on it are trying to stretch the material. Compression is when the forces acting on an object are trying to squash it.

$$\boldsymbol{\sigma} = \frac{\boldsymbol{F}}{\boldsymbol{A}} \qquad (4.13)$$

stress = stress measured in Nm^{-2} or pascals (Pa)
F = force in newtons (N)
A = cross-sectional area in m^2

The ratio of extension to original length, it has no units as it is a ratio of two lengths measured in meters**.**

$$\varepsilon = \frac{\Delta \boldsymbol{L}}{\boldsymbol{L}} \qquad (4.14)$$

ε = strain,

L = the original length

ΔL = stretched length

The relationship between the stress and strain that a particular material displays is known as that particular material's stress–strain curve. It is unique for each material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading (stress).

Poisson's ratio(ν): the ratio of lateral or transverse strain to the longitudinal strain.

$$\nu = - \varepsilon_t \backslash \varepsilon_a \quad (4.15)$$

Young Modulus(E): it is the modulus of elasticity. This means it is a number which represents how easy it is to deform (stretch a material). It measured in pascals (Pa)

$$E = \frac{\sigma}{\varepsilon} \quad (4.16)$$

4.5.1 Brittle and ductile materials

Materials may be divided into two broad categories:

- Brittle Material:

Materials that exhibit very little inelastic deformation. In other words, materials that fail in tension at relatively low values of strain are considered brittle. Brittle materials include concrete, stone, cast iron, glass, bone and plaster.

Brittle materials often have relatively large Young's moduli and ultimate stresses. Brittle materials fail suddenly and without much warning.

- Ductile Material:

Materials that are capable of undergoing large strains before failure. An advantage of ductile materials is that visible distortions may occur if the loads before too large. Ductile materials are also capable of absorbing large amounts of energy prior to failure. Ductile materials include mild steel, aluminum and some of its alloys, copper, magnesium, nickel, brass, bronze and many others.

Ductile materials exhibits large strains and yielding before they fail and often have relatively small Young's moduli and ultimate stresses.

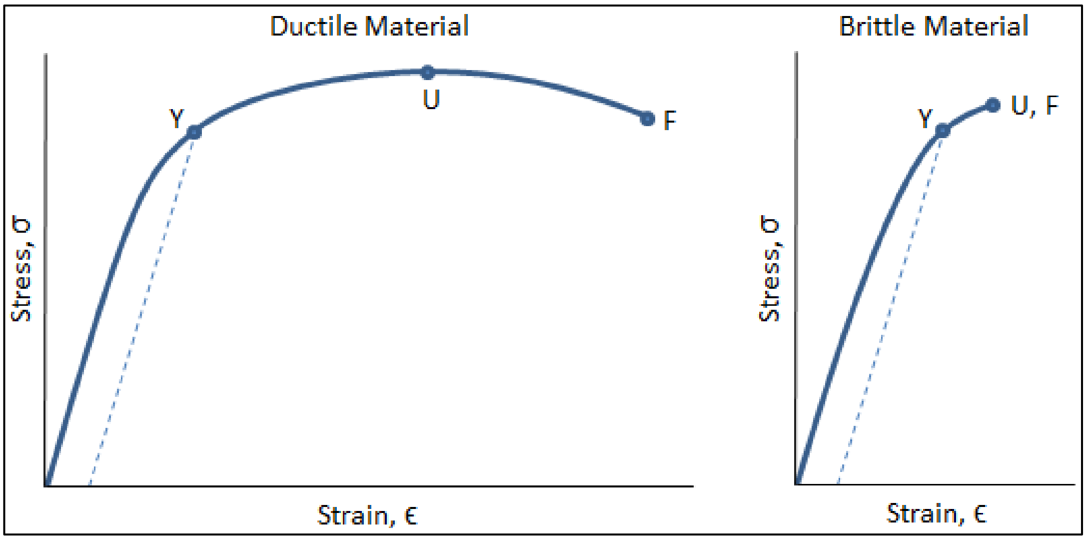


Figure4.5: Ductile and Brittle stress-strain curve

- Y: This is the yield point, which represents the value of stress above which the strain will begin to increase rapidly. The stress at the yield point is called the yield strength, S_{ty}.
- U: This point corresponds to the ultimate strength, S_{tu}, which is the maximum value of stress on the stress-strain diagram. The ultimate strength is also referred to as the tensile strength.
- F: This is the fracture point or the break point, which is the point at which the material fails and separates into two pieces.

4.6 Deformation

Deformation refers to any changes in the shape or size of an object due to

- An applied force (the deformation energy in this case is transferred through work) or
- A change in temperature (the deformation energy in this case is transferred through heat).

The first case can be a result of tensile (pulling) forces, compressive (pushing) forces, shear, bending or torsion (twisting). Deformation is often described as strain.

As deformation occurs, internal inter-molecular forces arise that oppose the applied force. If the applied force is not too great, these forces may be sufficient to completely resist the applied force and allow the object to assume a new equilibrium state and to return to its original state when the load is removed. A larger applied force may lead to a permanent deformation of the object or even to its structural failure.

Permanent deformation is irreversible; the deformation stays even after removal of the applied forces, it is called plastic deformation.

While the temporary deformation is recoverable as it disappears after the removal of applied forces. Temporary deformation is also called elastic deformation.

4.8 Finite Element Simulations with Impact Pressures:

Traumatic head injuries are basically caused due to transmission of impact pressures from the outer layer (scalp) to the inner layers (skull, Dura and brain) of the human head.

If one is able to measure these pressures or impact forces on-field and at the time of impact then through this research project concept one will be able to predict whether that individual will have a concussion or any other type of brain injury. A relationship between accelerations causing concussion and consequent impact pressures can be used for prediction [26].

Chapter Five

Methodology And Results

5.1 ANSYS Software

5.1.1 Impact in ANSYS

5.1.2 Explicit Integration Methods

5.1.2.1 Explicit dynamics applications

5.1.2.2 The solution strategy

5.1.2.3 Explicit transient dynamics

5.1.2.4 Explicit time integration

5.1.3 Material Assignments (Engineering Data)

5.1.4 Import Geometry

5.1.5 Generation Mesh

5.2 Results

5.1 ANSYS Software

ANSYS is a general purpose software, used to simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic for engineer sit enables to simulate tests or working conditions, enables to test in virtual environment before manufacturing prototypes of products. Furthermore, determining and improving weak points, and foreseeing probable problems are possible by 3D simulations in virtual environment.

ANSYS structural analysis software enables to solve complex structural engineering problems and make better, faster design decisions. With the finite element analysis (FEA) tools available in the suite, you can customize and automate solutions for structural[31].

5.1.1 Impact in ANSYS

Impact between two or more bodies is modeled by the ANSYS structural of programs, including mechanical, explicit dynamics and rigid body dynamics. These programs calculate the forces between two or more colliding bodies and the resultant deformation or damage. Explicit Dynamics generally is used for high speed interactions[31].

ANSYS was chosen considering the availability of software licenses in the university and compatibility of the software to import the available head model file.
During this study, we learned about the ANSYS Program so that we learned about it in general , how to introduce the skull model and make some adjustments to it.

5.1.2 Explicit dynamics

5.1.2.1 Explicit dynamics applications

The Explicit Dynamics system is designed to simulate nonlinear structural mechanics applications involving one or more of the following:

- Impact from low [1m/s] to very high velocity [5000m/s].
- Stress wave propagation.
- High frequency dynamic response.
- Large deformations and geometric nonlinearities.
- Complex contact conditions.

- Complex material behavior including material damage and failure.
- Nonlinear structural response including buckling.
- Failure of bonds, welds, and fasteners.
- Shock wave propagation through solids and liquids.
- Rigid and flexible bodies.

Explicit Dynamics is most suited to events which take place over short periods of time, a few milliseconds or less. Events which last more than 1 second can be modeled; however, long run times can be expected. Techniques such as mass scaling and dynamic relaxation are available to improve the efficiency of simulations with long durations.

5.1.2.2 The solution strategy

In an Explicit Dynamics solution, we start with a discretized domain (mesh) with assigned material properties, loads, constraints and initial conditions. This initial state, when integrated in time, will produce motion at the node points in the mesh. The following steps explain the solution strategy in the explicit dynamics analysis system:

- The motion of the node points produces deformation in the elements of the mesh.
- The deformation results in a change in volume (hence density) of the material in each element.
- The rate of deformation is used to derive material strain rates using various element formulations.
- Constitutive laws take the material strain rates and derive resultant material stresses.
- The material stresses are transformed back into nodal forces using various element formulations.
- External nodal forces are computed from boundary conditions, loads and contact (body interaction).
- The nodal forces are divided by nodal mass to produce nodal accelerations.
- The accelerations are integrated Explicitly in time to produce new nodal velocities.
- The nodal velocities are integrated Explicitly in time to produce new nodal positions.
- The solution process (Cycle) is repeated until a user defined time is reached. Figure () shows the solution process (cycle) algorithm.

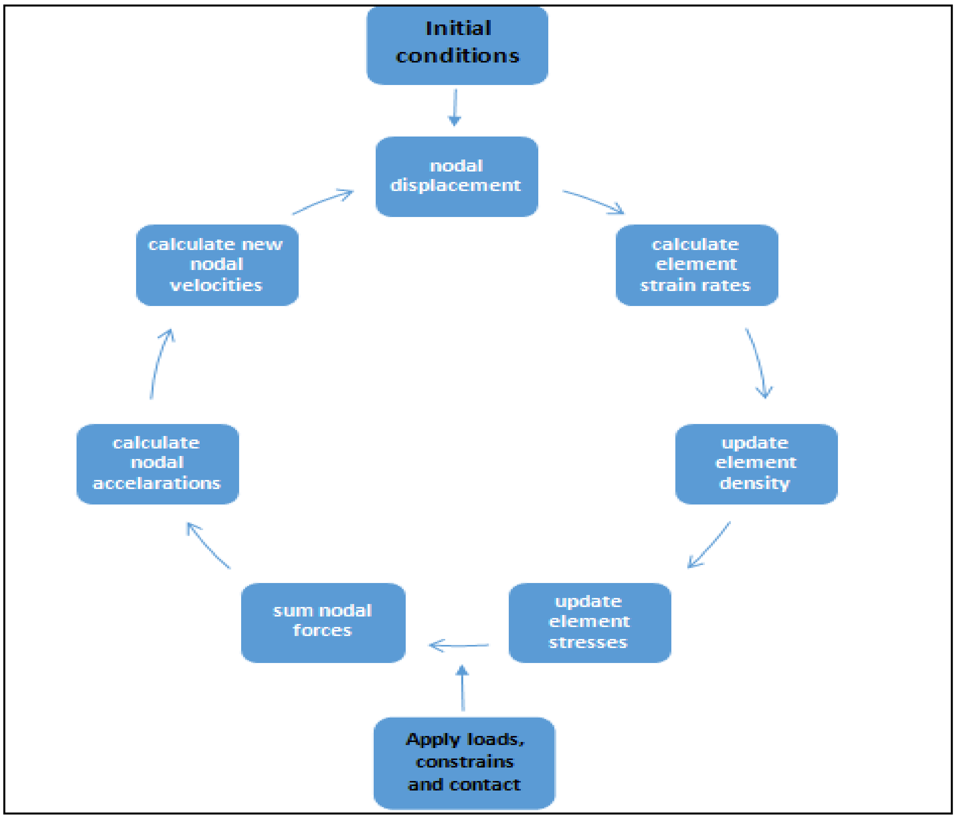


Figure 5.1: Explicit dynamics solution algorithm.

5.1.2.3 Explicit transient dynamics

The partial differential equations to be solved in an Explicit Dynamics analysis express the conservation of mass, momentum, and energy in Lagrangian coordinates. These, together with a material model and a set of initial and boundary conditions, define the complete solution of the problem.

For the Lagrangian formulations currently available in the Explicit Dynamics system, the mesh moves and distorts with the material it models and conservation of mass is automatically satisfied. The density at any time can be determined from the current volume of the zone and its initial mass, as:

$$\frac{\rho_0 V_0}{V} = \frac{m}{V} \qquad (5\text{-}1)$$

The partial differential equations that express the conservation of momentum relate the acceleration to the stress tensor σ_{ij} , shown as:

$$\boldsymbol{\rho\ddot{x} = b_x + \frac{\partial\sigma_{xx}}{\partial x} + \frac{\partial\sigma_{xy}}{\partial y} + \frac{\partial\sigma_{xz}}{\partial z}} \tag{5-2}$$

$$\boldsymbol{\rho\ddot{y} = b_y + \frac{\partial\sigma_{yx}}{\partial x} + \frac{\partial\sigma_{yy}}{\partial y} + \frac{\partial\sigma_{yz}}{\partial z}} \tag{5-3}$$

$$\boldsymbol{\rho\ddot{z} = b_z + \frac{\partial\sigma_{zx}}{\partial x} + \frac{\partial\sigma_{zy}}{\partial y} + \frac{\partial\sigma_{zz}}{\partial z}} \tag{5-4}$$

Conservation of energy is expressed via:

$$\boldsymbol{\dot{e} = \frac{1}{\rho}(\sigma_{xx}\dot{\varepsilon}_{xx} + \sigma_{yy}\dot{\varepsilon}_{yy} + \sigma_{zz}\dot{\varepsilon}_{zz} + 2\sigma_{xy}\dot{\varepsilon}_{xy} + 2\sigma_{yz}\dot{\varepsilon}_{yz} + 2\sigma_{zx}\dot{\varepsilon}_{zx})} \tag{5-5}$$

These equations are solved explicitly for each element in the model, based on input values at the end of the previous time step. Small time increments are used to ensure stability and accuracy of the solution. Note that in Explicit Dynamics we do not seek any form of equilibrium; we simply take results from the previous time point to predict results at the next time point. There is no requirement for iteration.

In a well-posed Explicit Dynamics simulation, mass, momentum, and energy should be conserved. Only mass and momentum conservation is enforced. Energy is accumulated over time and conservation is monitored during the solution. Feedback on the quality of the solution is provided via summaries of momentum and energy conservation (as opposed to convergent tolerances in implicit transient dynamics).

5.1.2.4 Explicit time integration

The Explicit Dynamic solver uses a central difference time integration scheme. After forces have been computed at the nodes of the mesh (resulting from internal stress, contact, or boundary conditions), the nodal accelerations are derived by equating acceleration to force divided by mass. Therefore the accelerations are :

$$\ddot{\boldsymbol{x}}_{\boldsymbol{i}} = \frac{\boldsymbol{F}_{\boldsymbol{i}}}{\boldsymbol{m}} + \boldsymbol{b}_{\boldsymbol{i}} \qquad (5\text{-}6)$$

Where:

$\ddot{x}_i$: are the components of nodal acceleration (i=1,2,3).

F_i : are the forces acting on the nodal points.

b_i : are the components of body acceleration.

m : is the mass attributed to the node.

With the accelerations at time (n) determined, the velocities at time (n+1/2) are found from:

$$\dot{x}_i^{n+1/2} = \dot{x}_i^{n-1/2} + \ddot{x}_i^n \Delta t^n \qquad (5\text{-}7)$$

and finally, the positions are updated to time (n+1) by integrating the velocities as shown:

$$x_i^{n+1} = x_i^n + \dot{x}_i^{n+1/2} \Delta t^{n+1/2} \qquad (5\text{-}8)$$

The advantages of using this method for time integration for nonlinear problems are:

- The equations become uncoupled and can be solved directly (explicitly). There is no requirement for iteration during time integration.
- No convergence checks are needed because the equations are uncoupled.
- No inversion of the stiffness matrix is required. All nonlinearities (including contact) are included in the internal force vector.

To ensure stability and accuracy of the solution, the size of the time step used in Explicit time integration is limited by the CFL (Courant-Friedrichs-Lewy) condition. This condition implies that the time step be limited such that a disturbance (stress wave) cannot travel farther than the smallest characteristic element dimension in the mesh, in a single time step. Thus the time step criteria for solution stability is:

$$\Delta \boldsymbol{t} \leq \boldsymbol{f} * \left[\frac{\boldsymbol{h}}{\boldsymbol{c}}\right]_{\boldsymbol{min}} \qquad (5\text{-}9)$$

Where:

Δt : is the time increment.

f : is the stability time step factor.

h : is the characteristic dimension of an element.

c : is the local material sound speed in an element.

We analyzed and calculation the force on the Explicit Dynamics; shown in figure 1

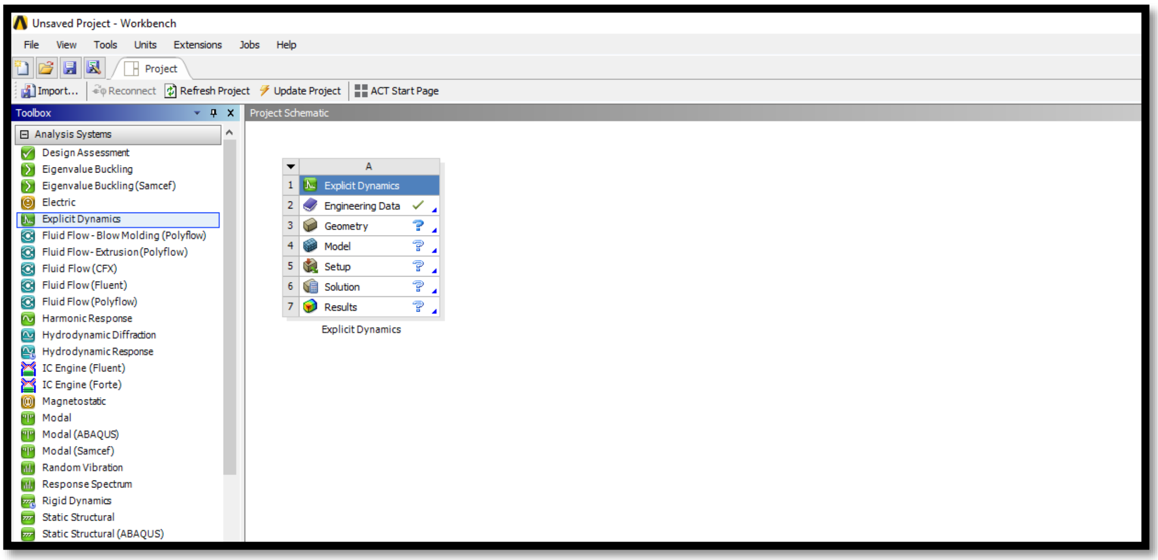


Figure5.2: Explicit Dynamics

5.1.3 Material Assignments (Engineering Data)

Human bone is highly heterogeneous and nonlinear in nature, so it is difficult to assign material properties along each direction of bone model. In biomechanics study, material can be assign in two ways, either in Mimics (Materialise Interactive Medical Image Control System) or in Finite element module. Here material properties are directly assigned in ANSYS by using finite element module. The table(6_1), show properties of material; Density, Young’s Modulus, Poisson’s Ratio.

Table 5.1: Elastic material properties of the skull

Parameter	Value
Density(Kg/m^3)	2070
young's modulus(Pa)	6.5 e^9
Poisson's Ratio	0.2

5.1.4 Import Geometry

Usually the type of the files is ".igs ", and edit model shown in figure 2

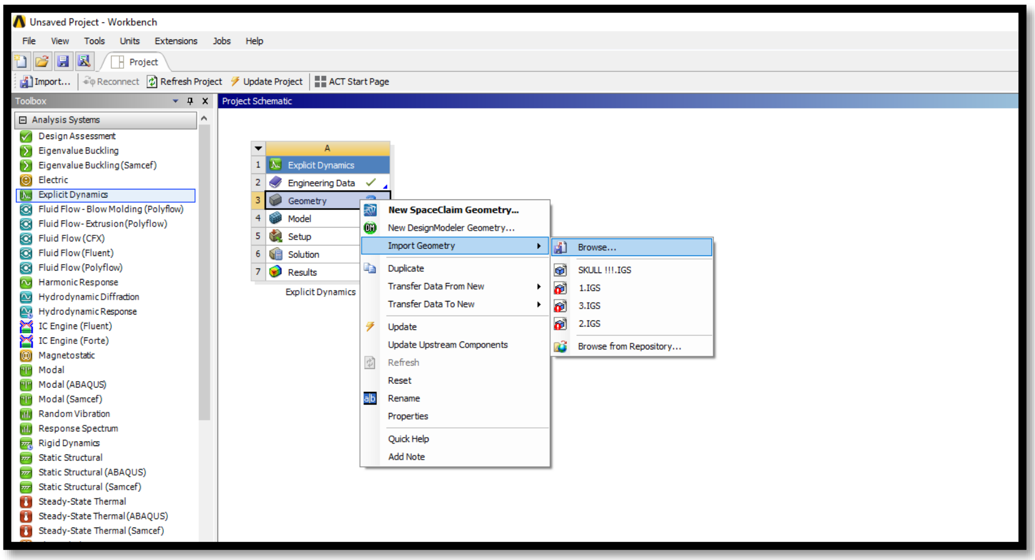


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Figure5.3: igs file

5.1.5 Generation Mesh

Mesh is a very important step required for Finite Element Analysis of the Skull model, an optimized mesh has been developed using model wizard in ANSYS Workbench. In automatic remeshed operation surface mesh of equilateral triangle is generated a proper setting and values have been executed in order to use smaller elements on proximities and curvatures for the model.

The numbers of tetrahedral elements used for the skull model are 23610, while the number of nodes is 4877 as shown in Figure5.3.

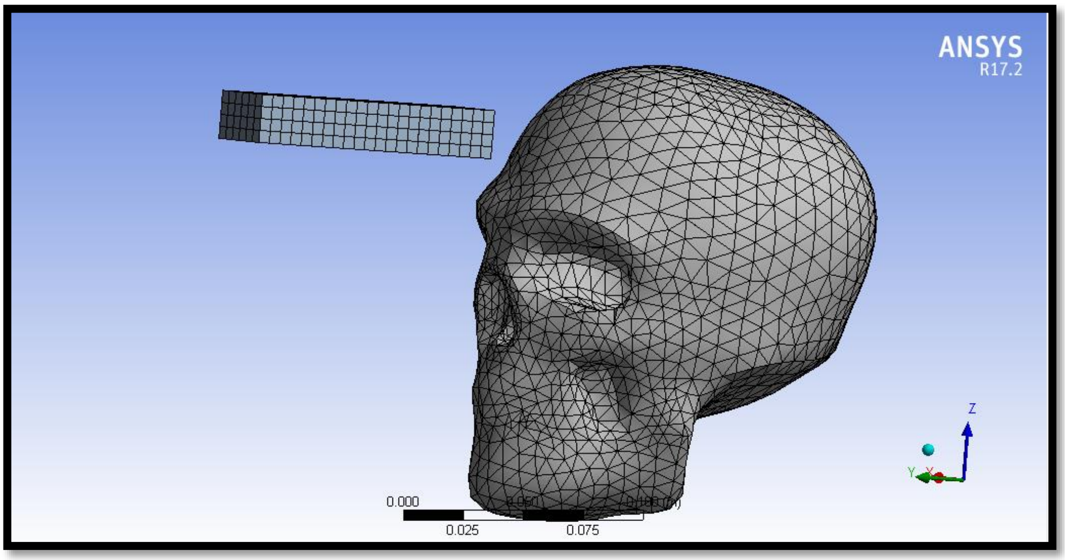


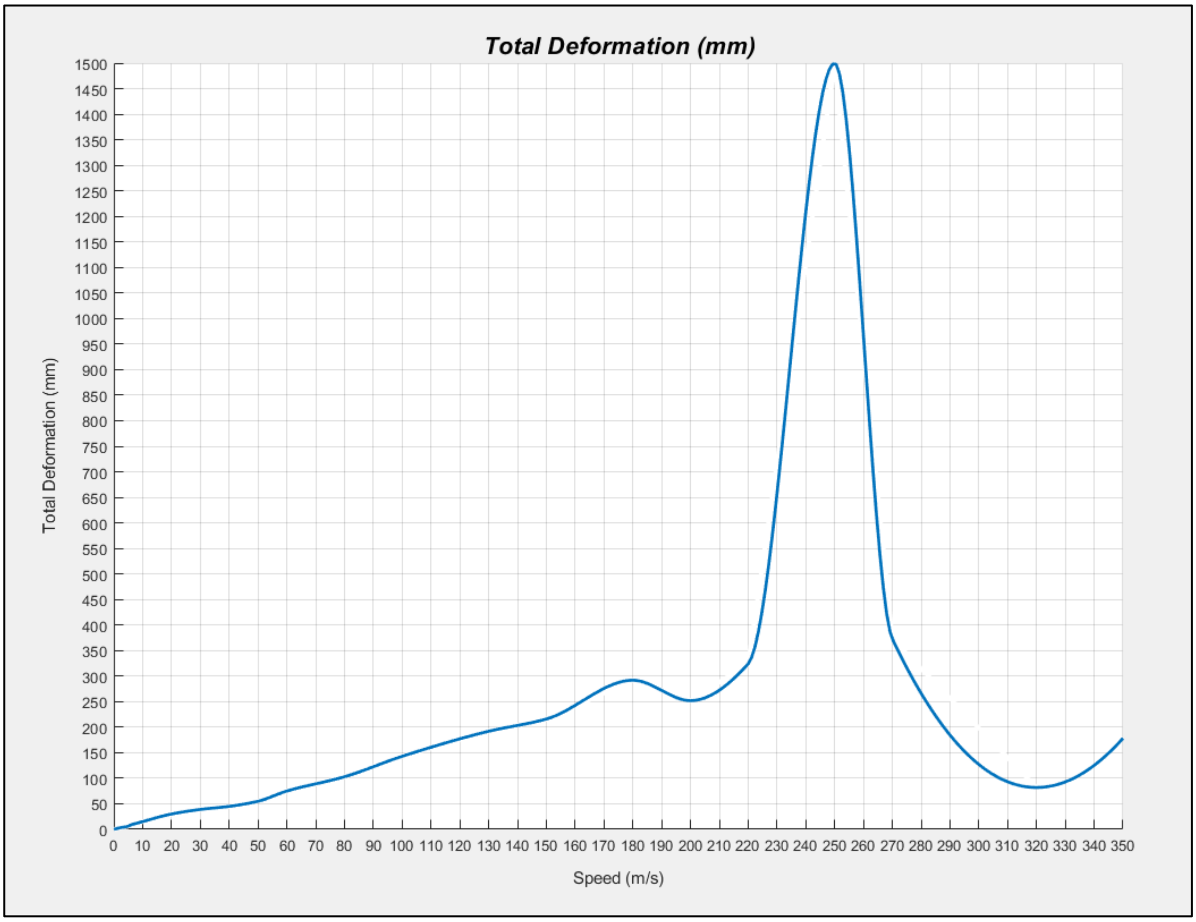
Figure5.4: meshing model

5.2 Results:

It may be noted that only static load(0.5Kg) applied on Skull. The results depend on the accuracy of FE model with reference to real conditions. This study investigates Equivalent (Von-Mises) stress, total deformation and Directional Deformation of skull for a weight of 4.5 Kg during normal position and the result be as the following:

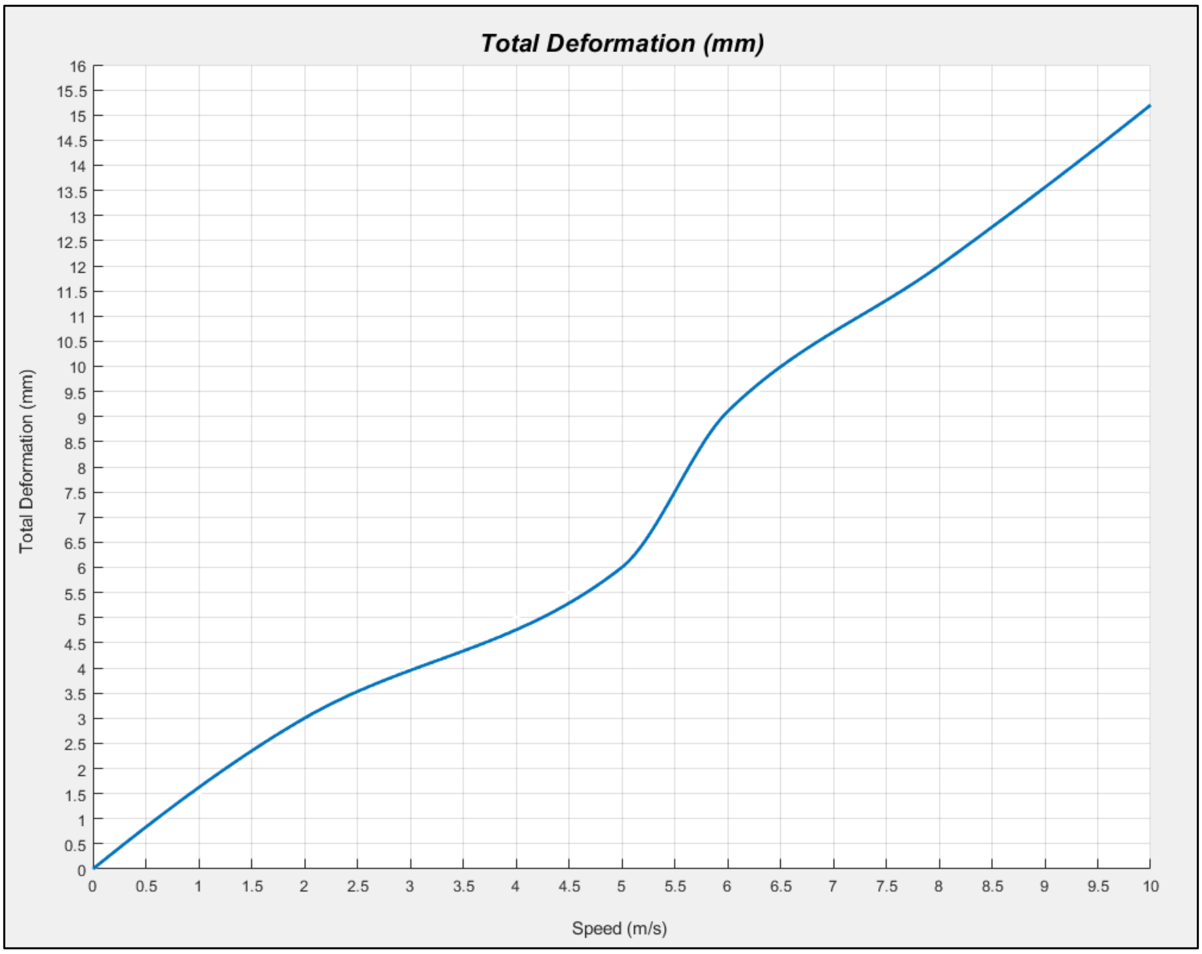
Table5.2: Total deformation

Speed of skull (m\s)	Total deformation (mm)
0	0
2	3
5	6
6	9.1
8	12
10	15.2
20	30
30	39
40	45
50	55
60	75
80	103
100	143
130	192
150	218
180	272
200	267
220	324
250	1500
260	373
320	82



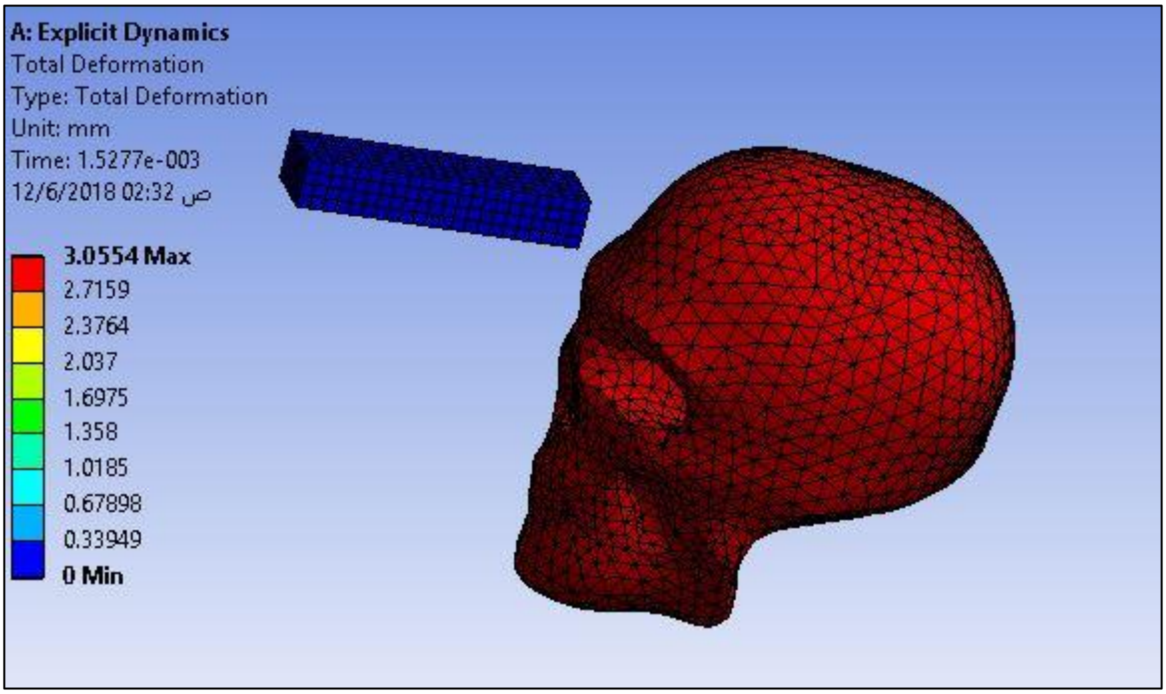
Now, we should divide previous curve into regions as following:

Region 1:

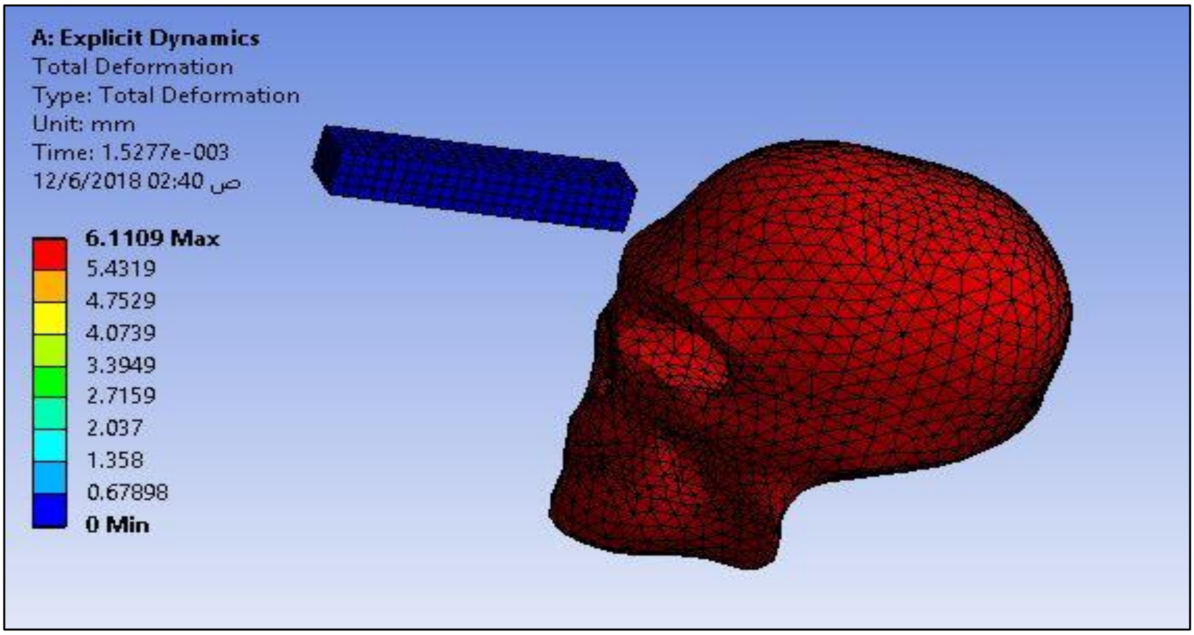


Low speed (1 m\s - 9 m\s) it considers safety speed because the deformation is low as is evident in the following pictures:

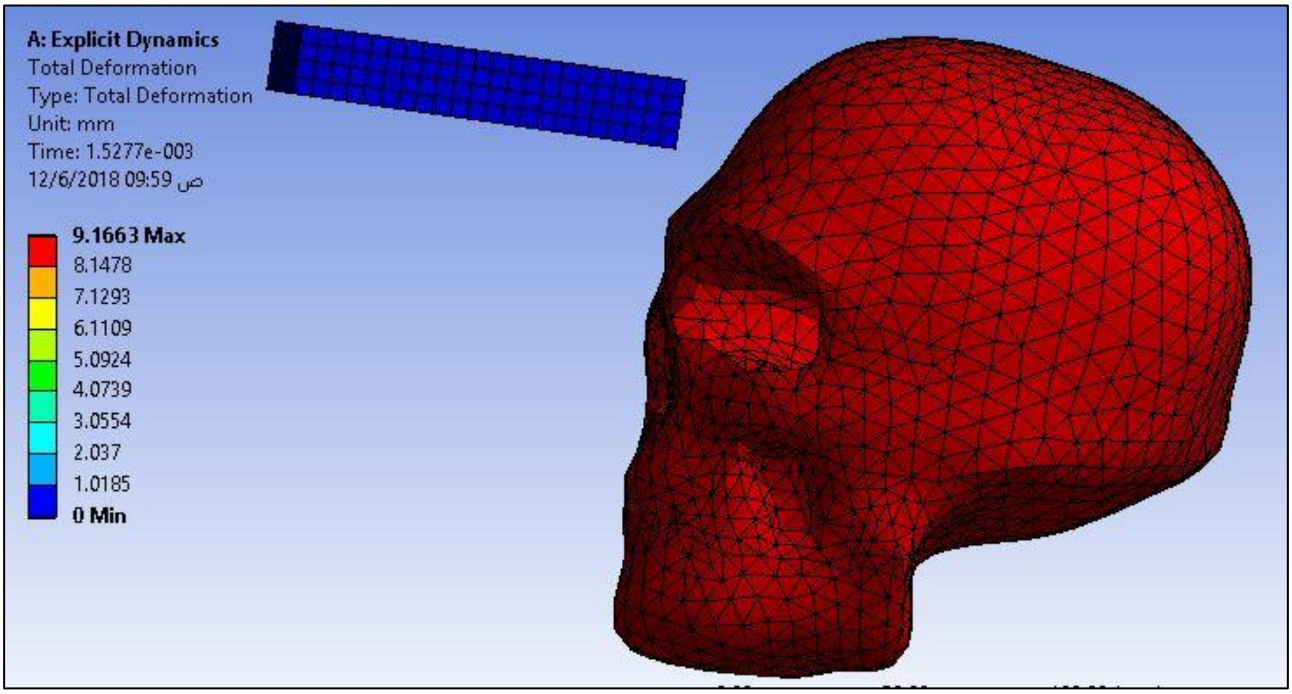
Deformation at 2m\s



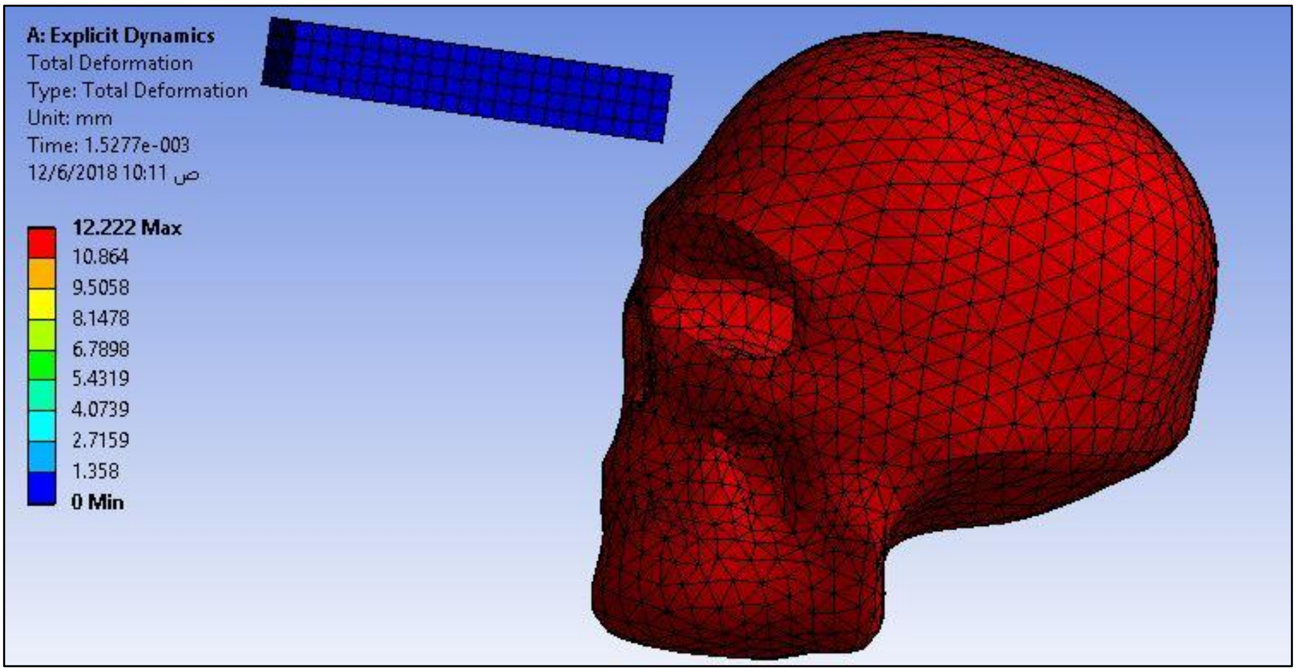
Deformation at 5m\s



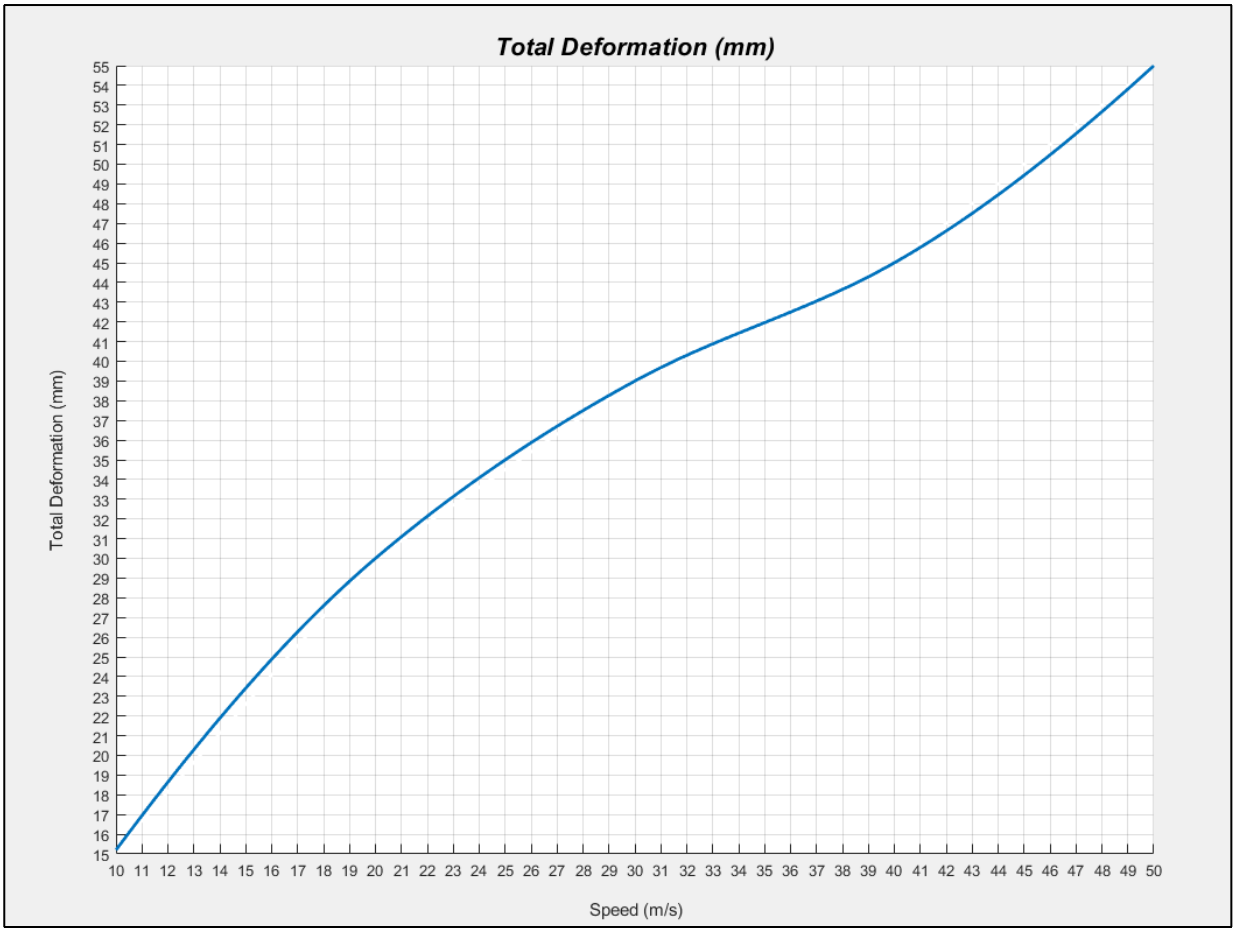
Deformation at 6 m\s



Deformation at 8 m\s

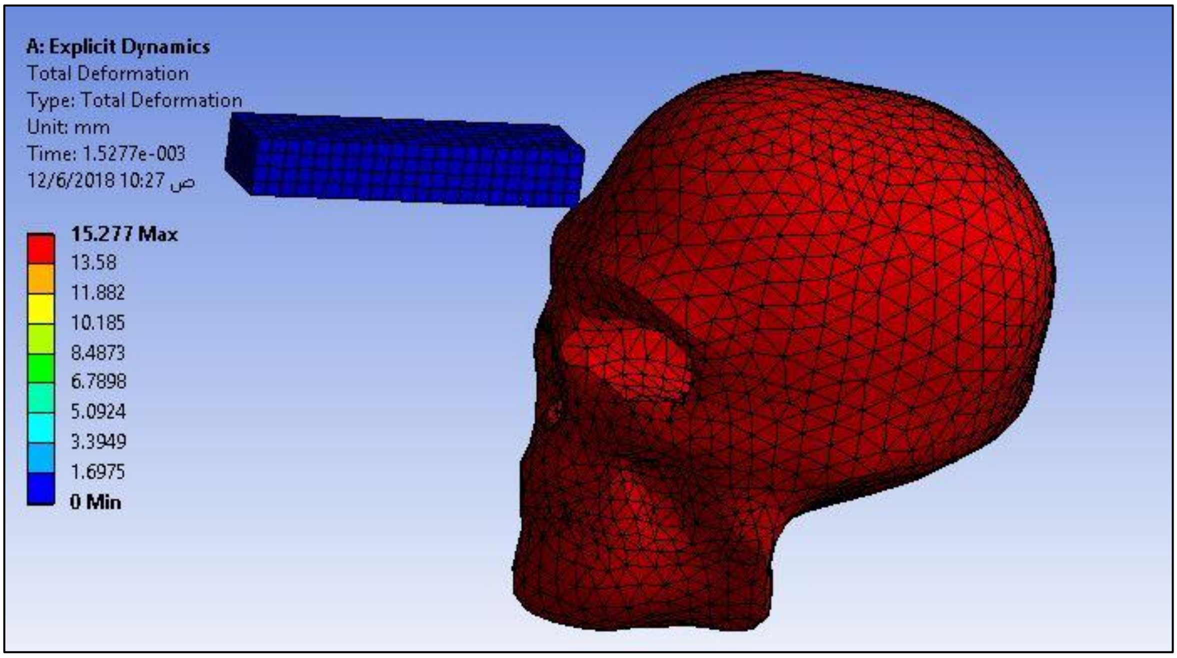


- **Region 2**

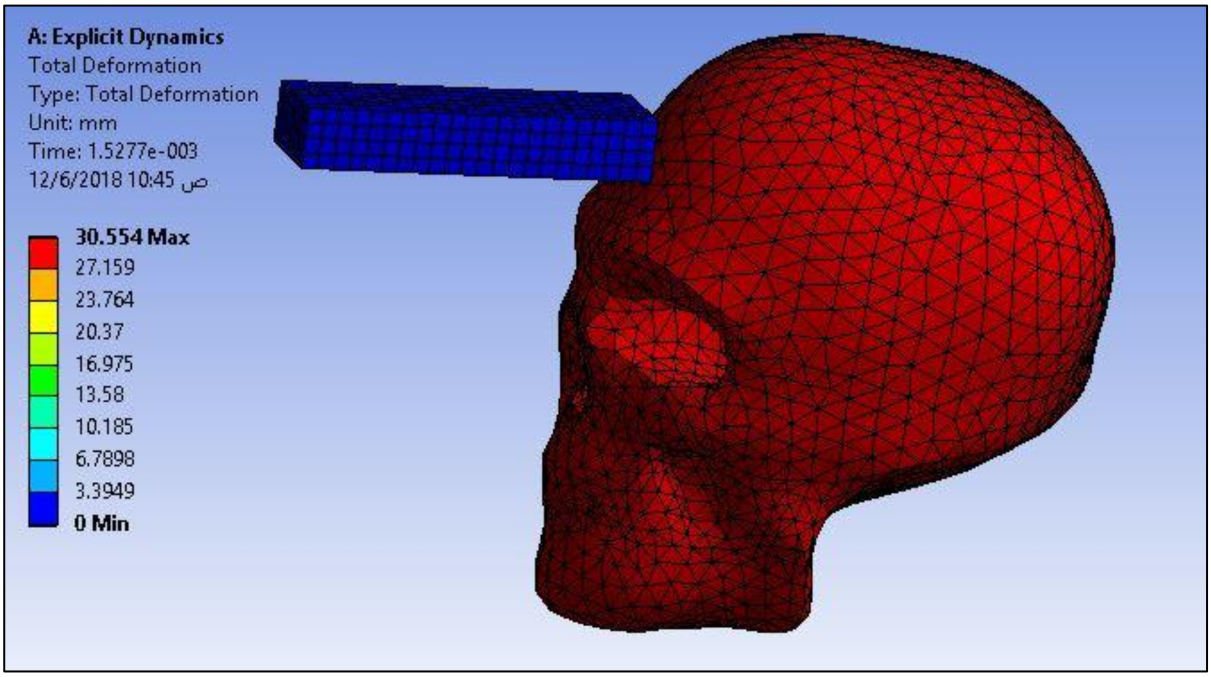


Medium speed (10 m\s - 49 m\s) the risk begins because of deformation increase as is evident in the following pictures:

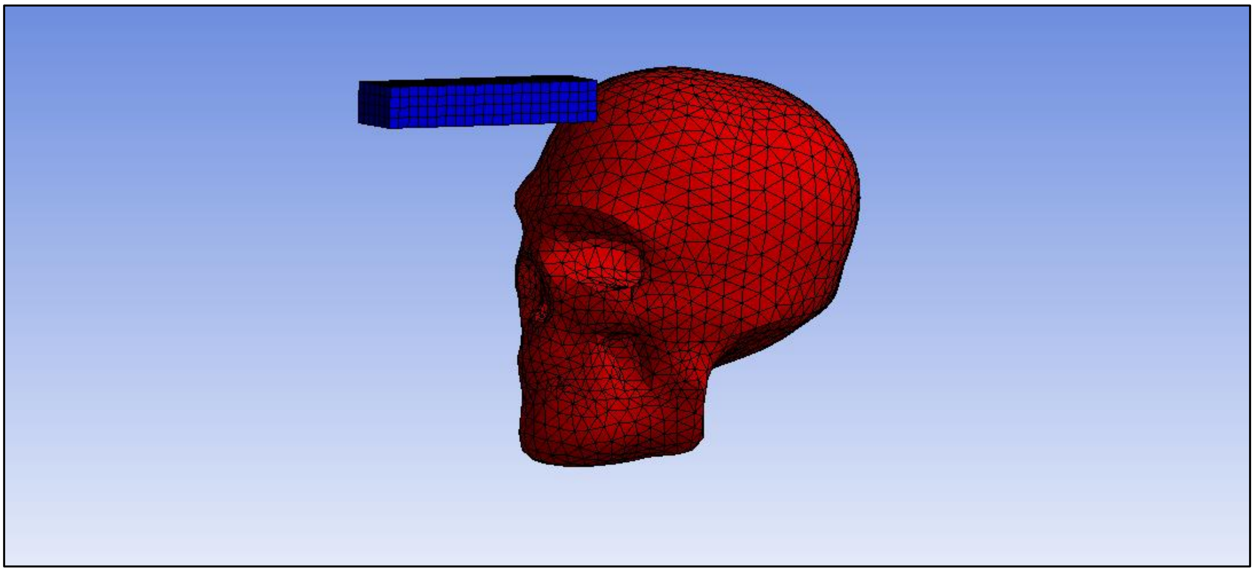
Deformation at 10m\s



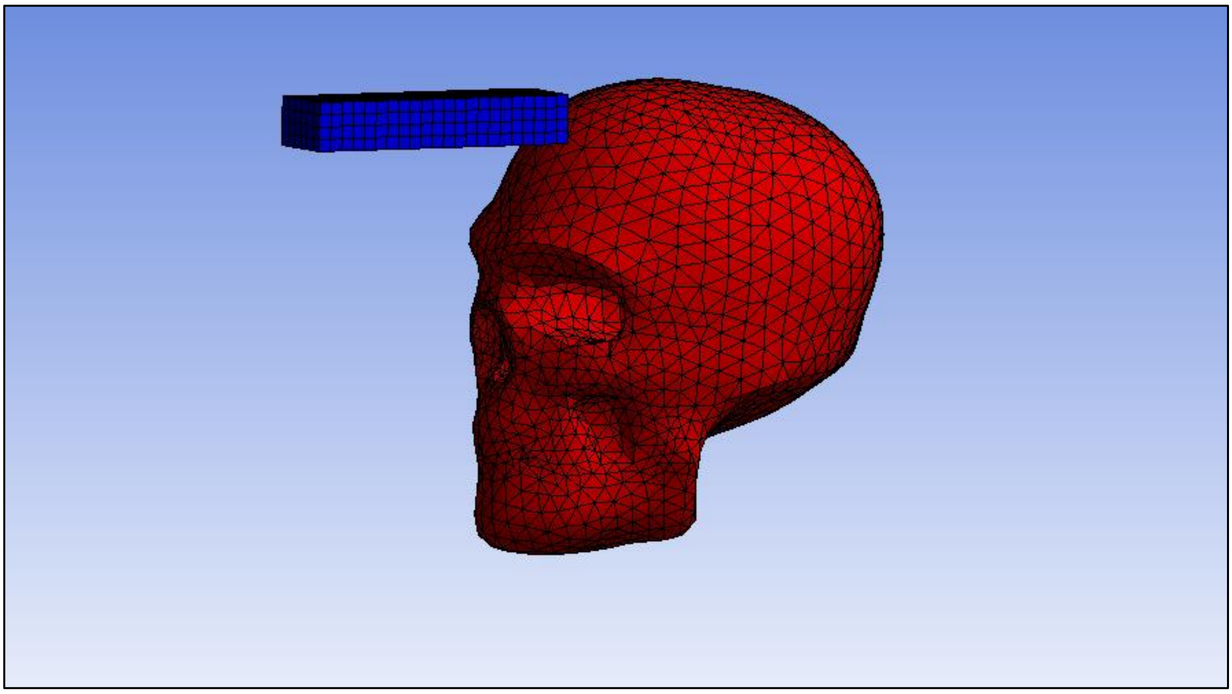
Deformation at 20 m\s



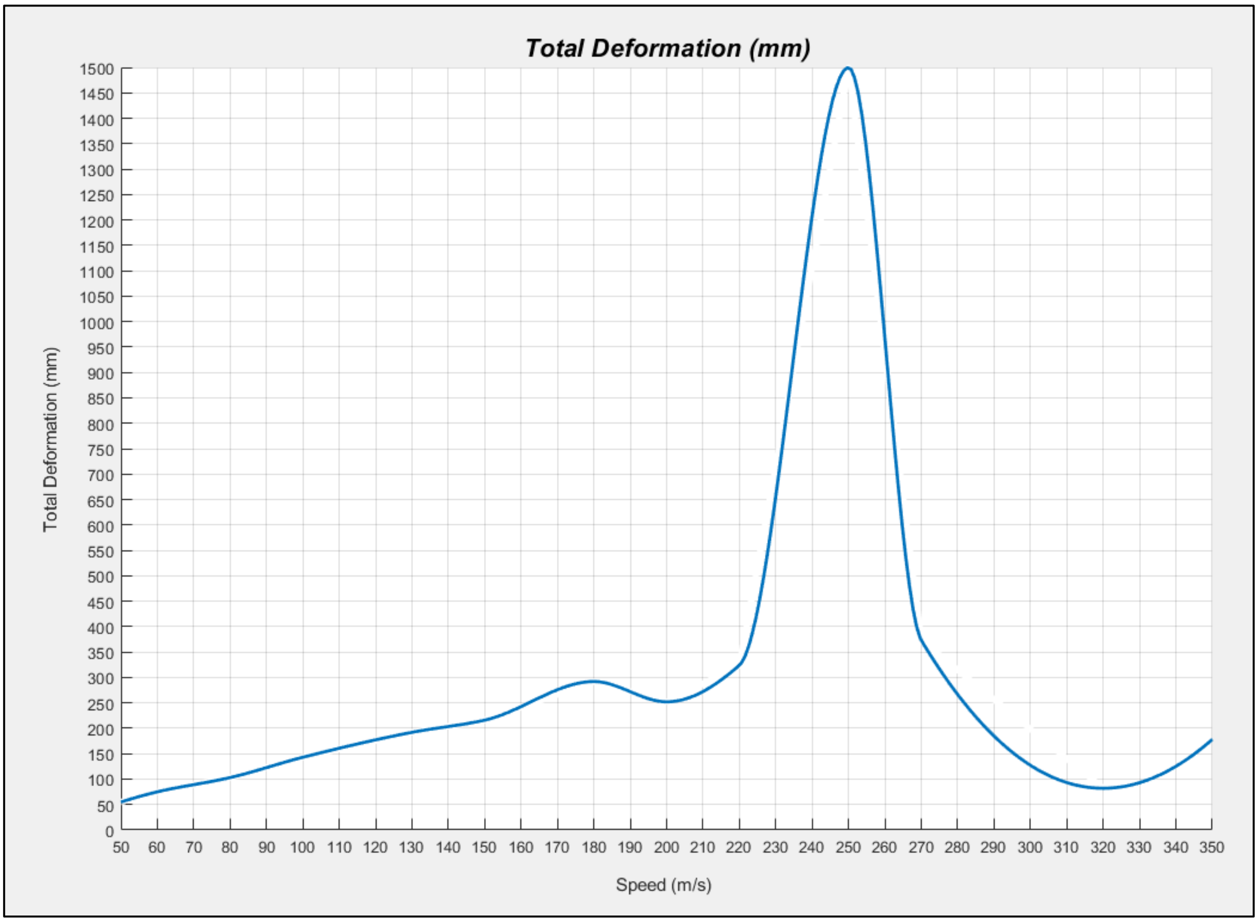
Deformation at 30 m\s



Deformation at 40 m\s

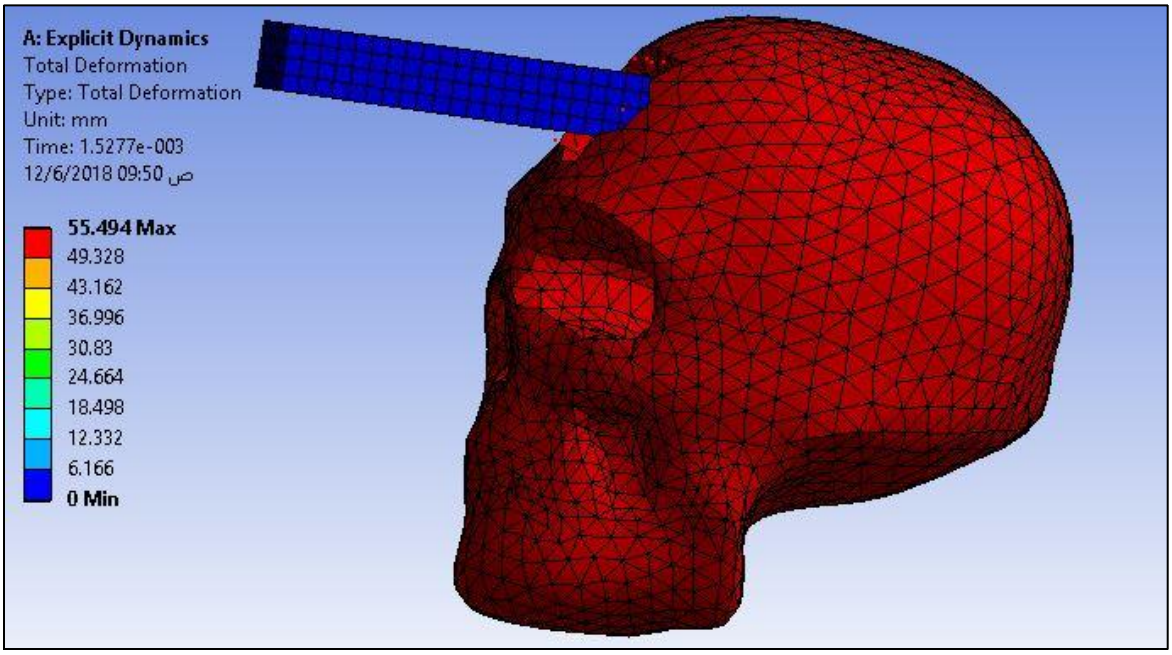


Region 3

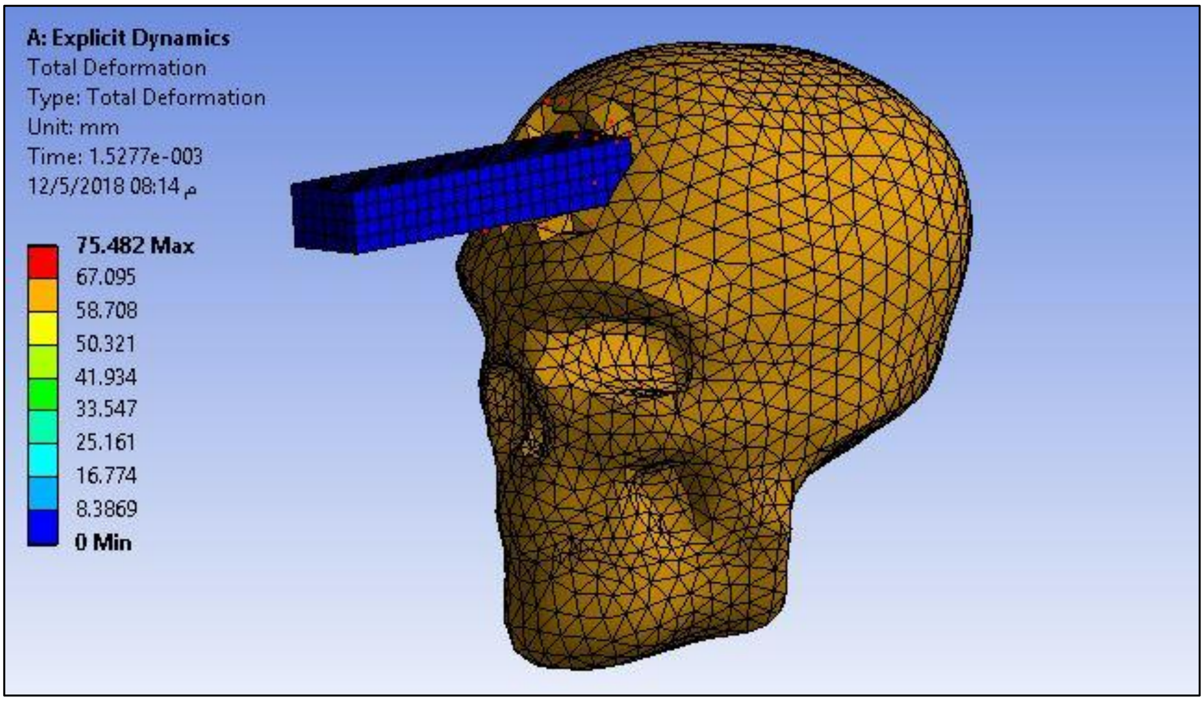


Starting at 50 and higher, it considers more dangerous than previous regions because the skull will break. The amount of deformation becomes an expression of displacement, as is evident in the following pictures:

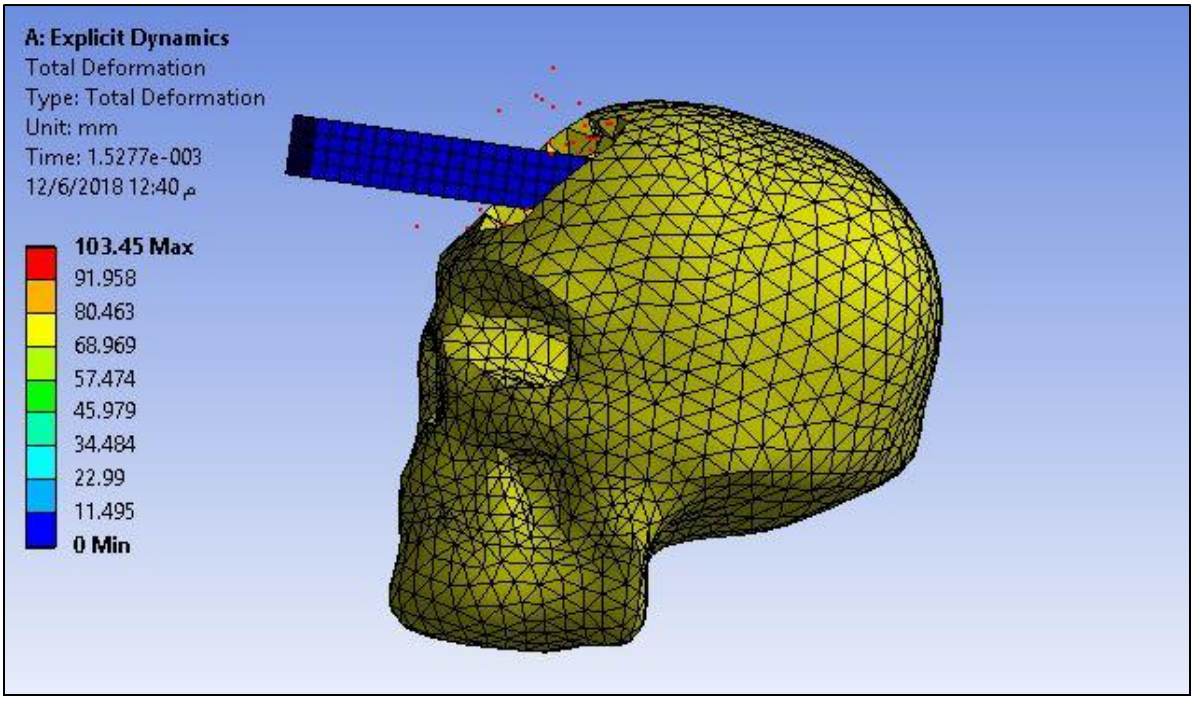
Deformation at 50 m\s



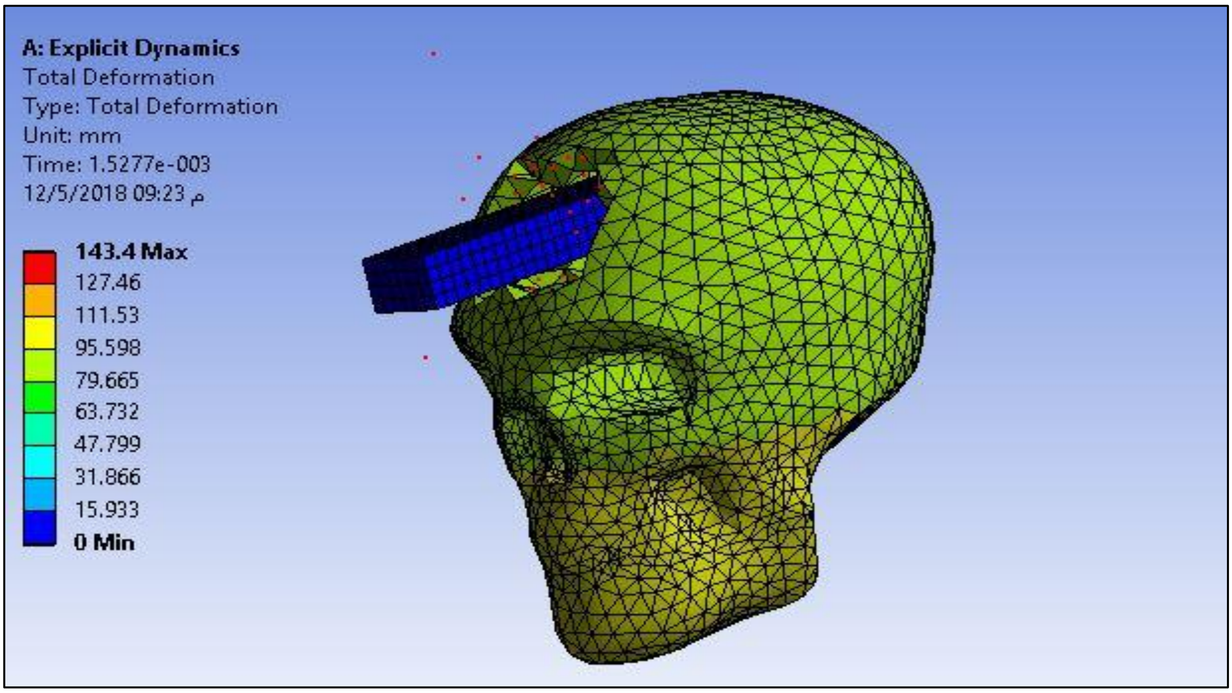
Deformation at 60 m\s



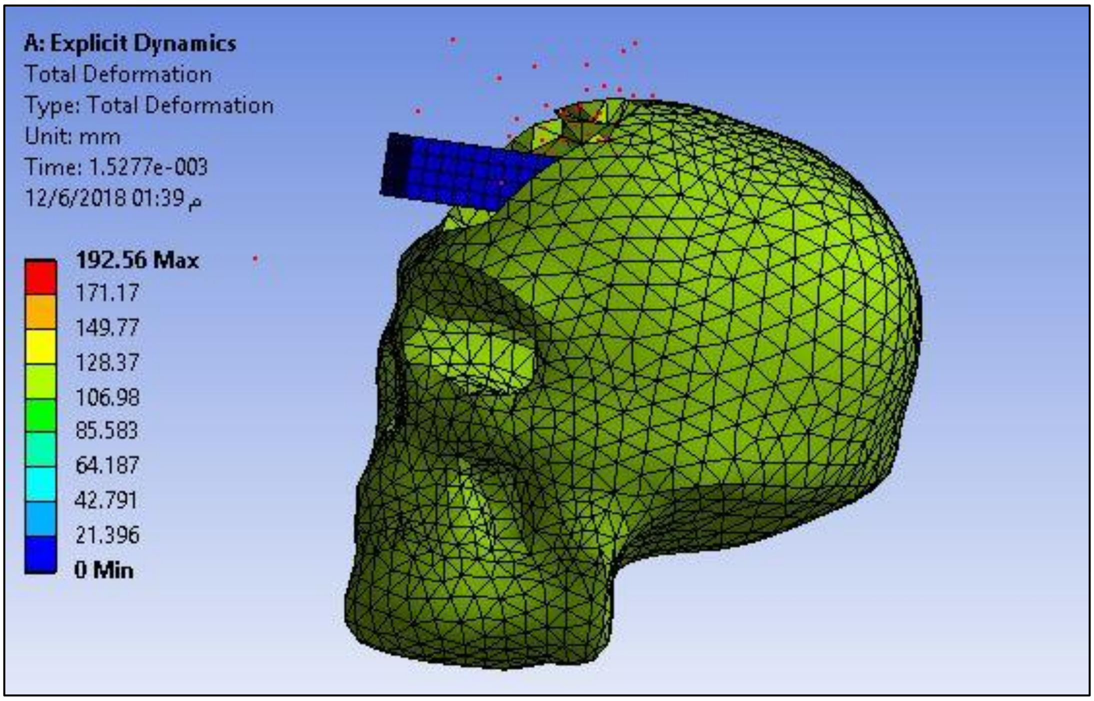
Deformation at 80 m\s



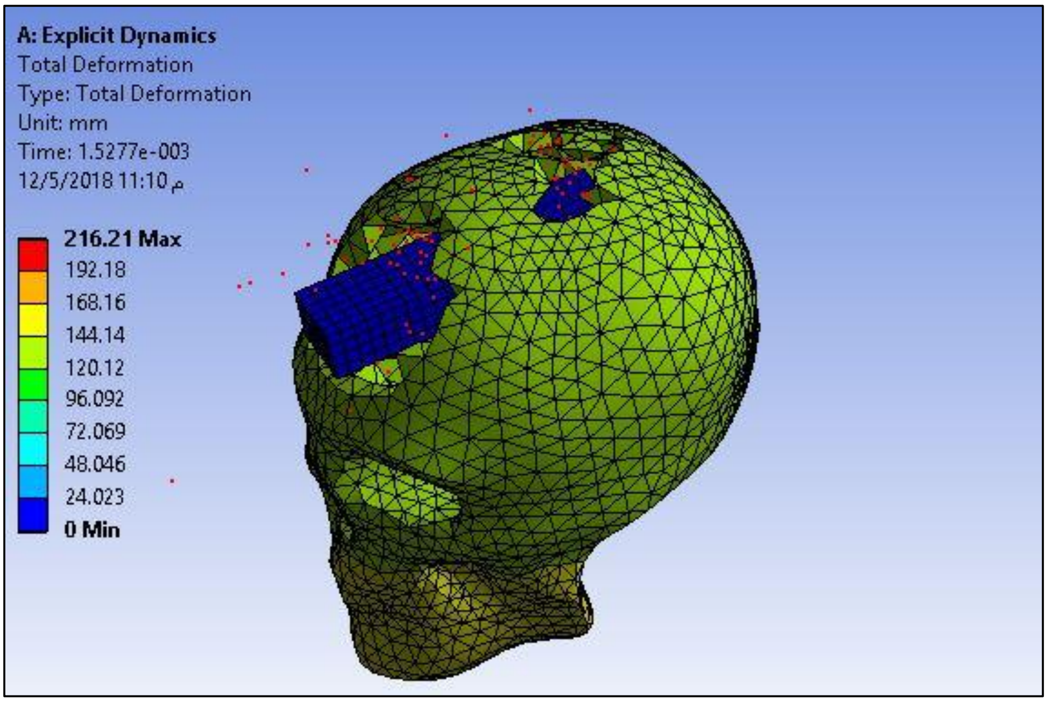
Deformation at 100 m\s



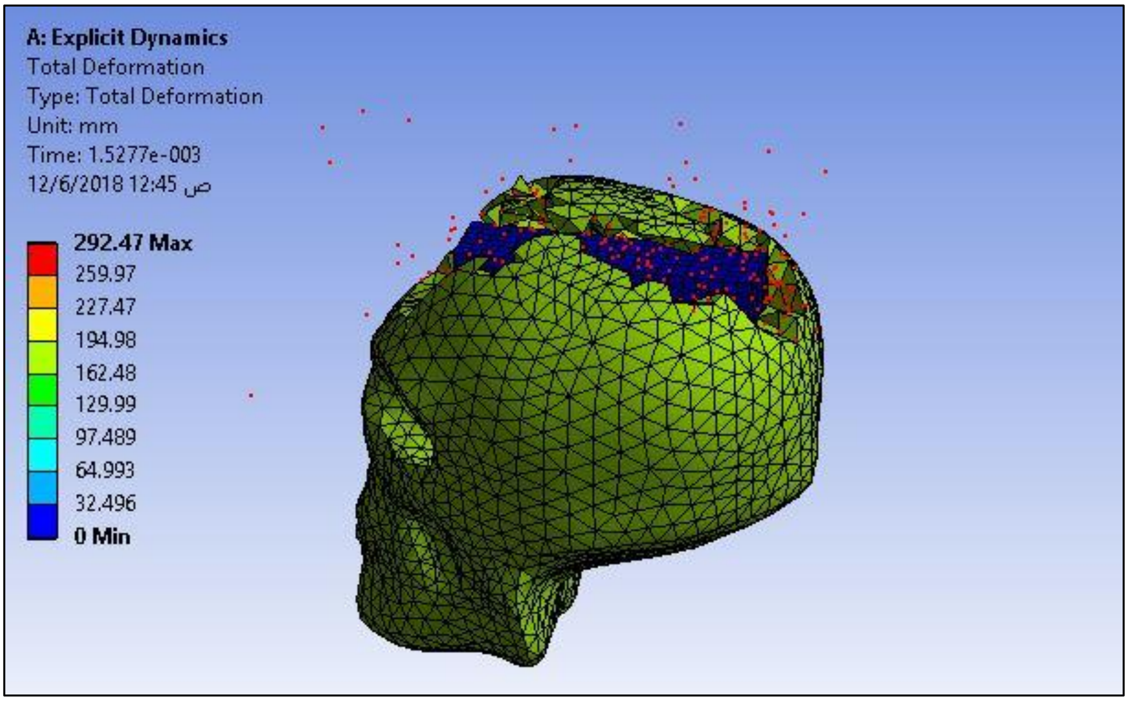
Deformation at 130 m\s



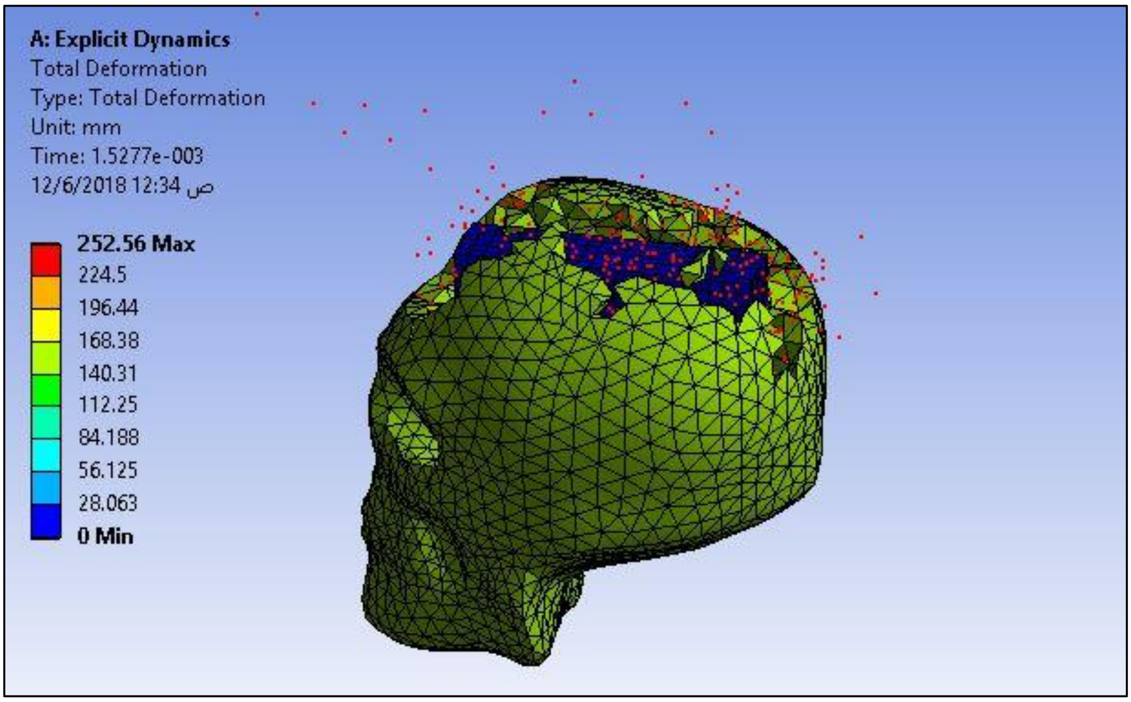
Deformation at 150 m\s



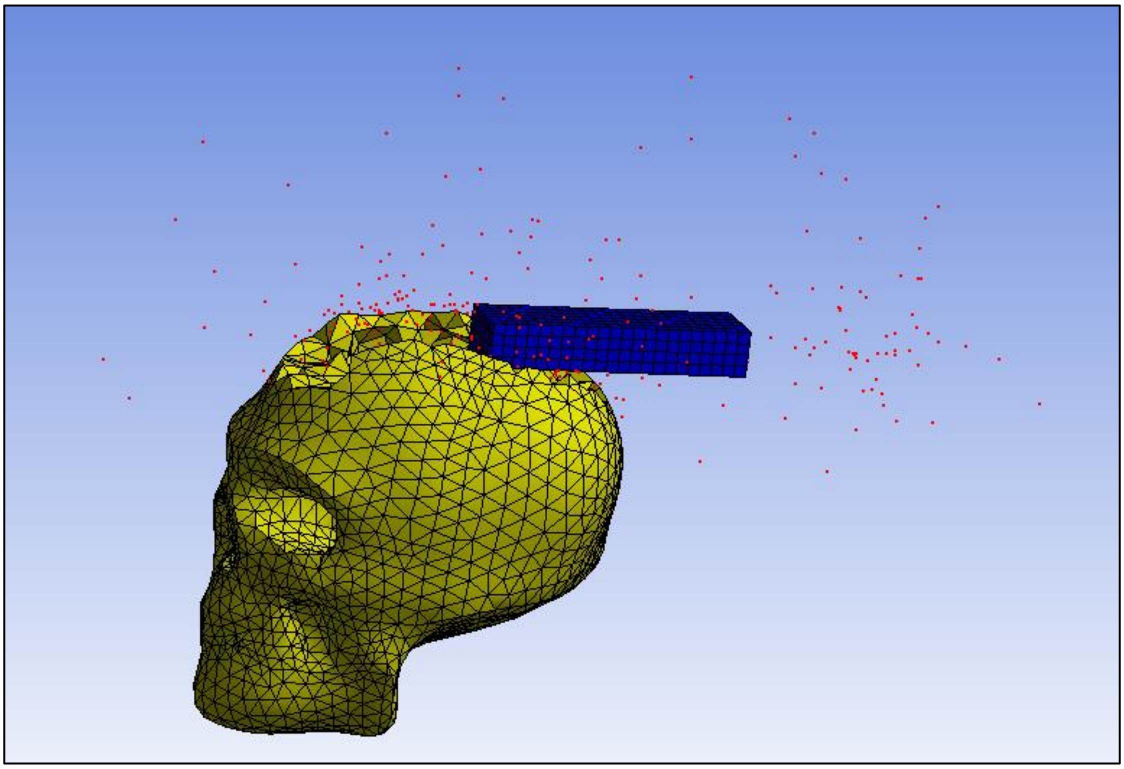
Deformation at 180 m\s



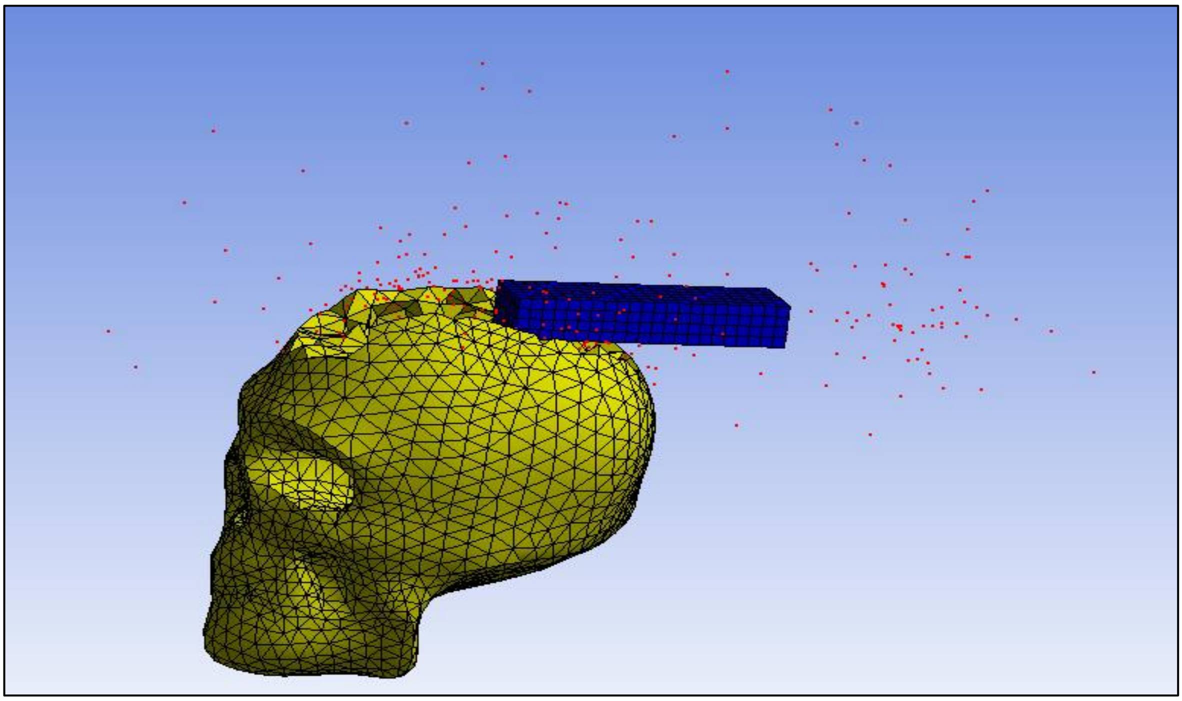
Deformation at 200 m\s



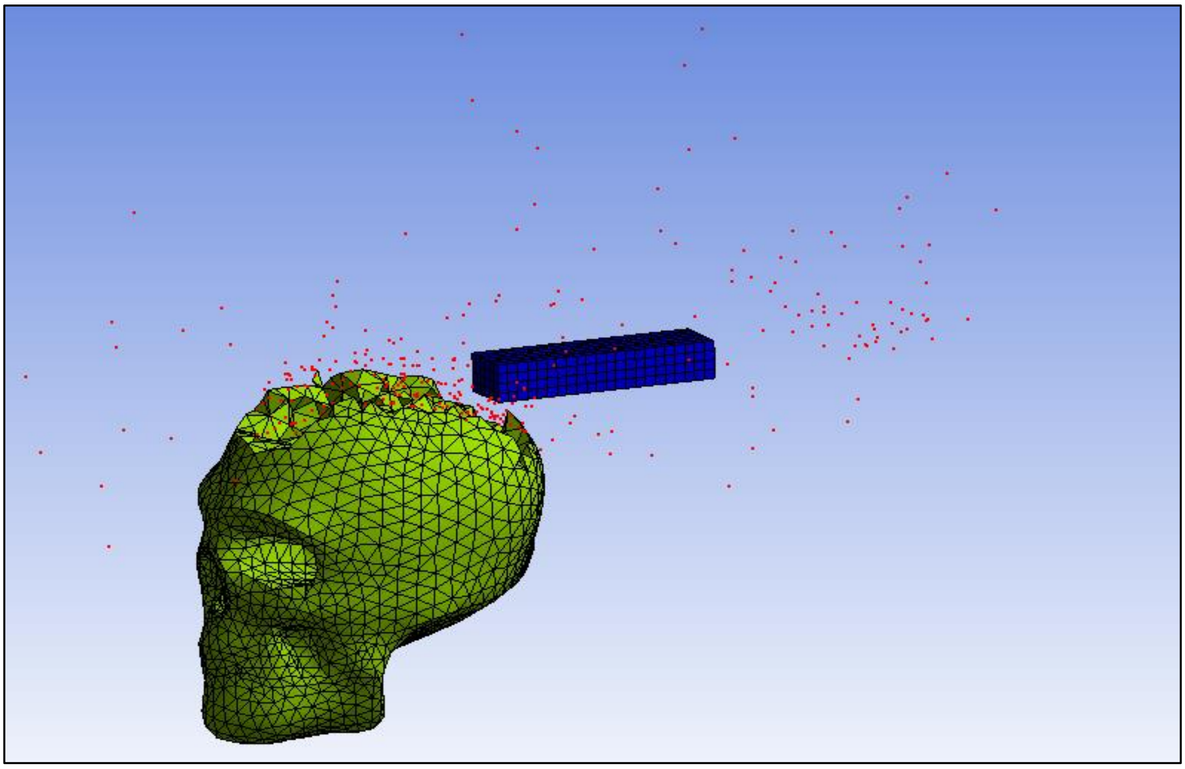
Deformation at 220 m\s



Deformation at 250 m\s



Deformation at 260 m\s



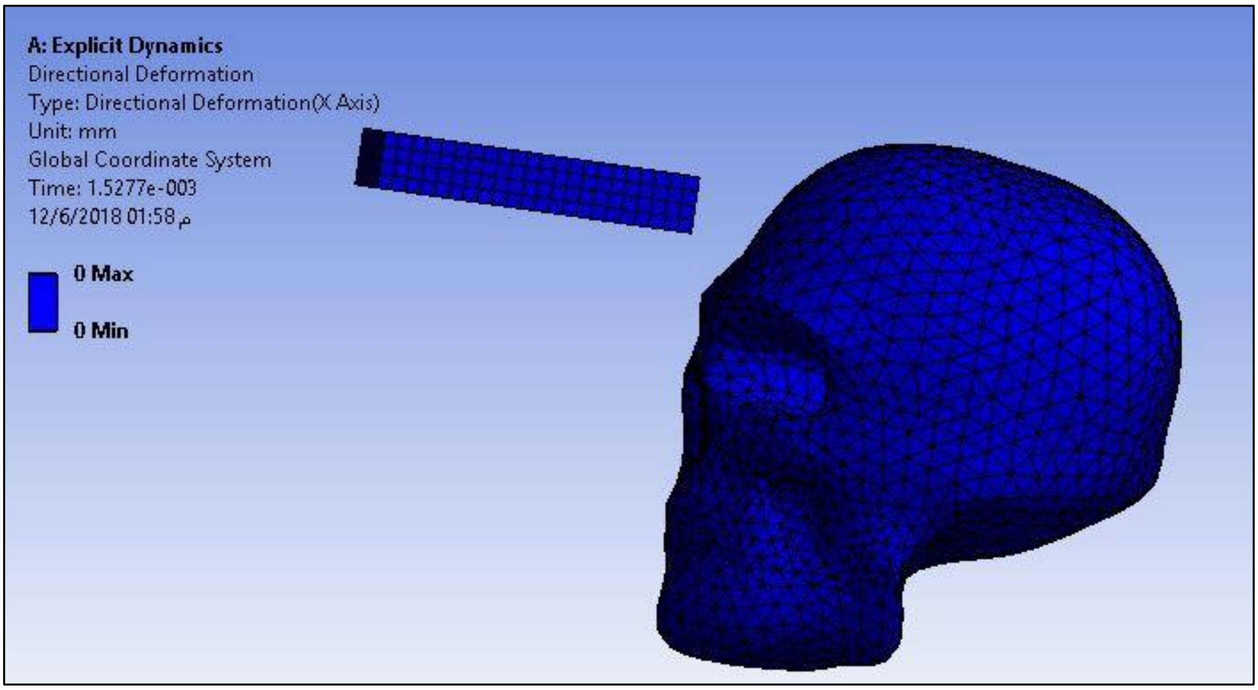
The Direction of Deformation:

Table5.3: Direction of deformation

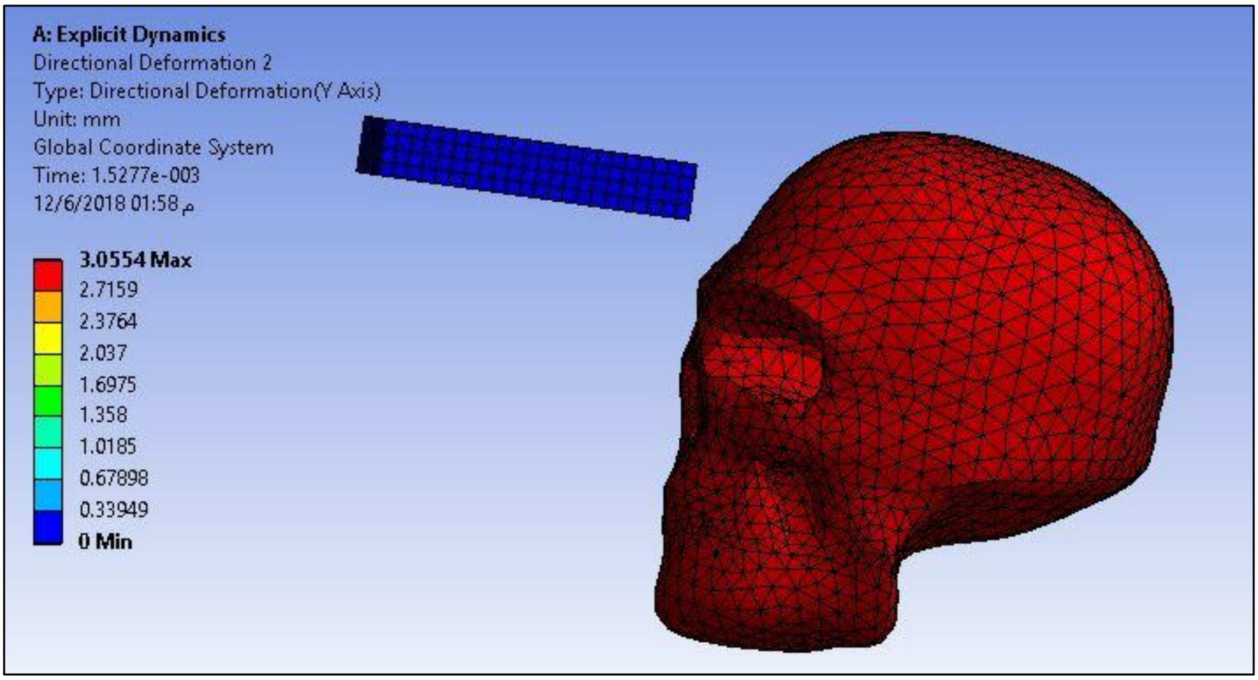
Velocity (m\s)	Direction X (mm)	Direction Y (mm)	Direction Z (mm)
0	0	0	0
2	0	3	0
5	0	6	0
6	0	9.1	0
8	0	12	0
10	0	15	0
20	0	21	0
30	0	32	0
50	0.6	54	0
80	5	88	6.5
100	4	110	16
130	1.5	147	59
150	5	164	45
180	2.3	179	90
200	9	212	66
220	66	233	100
250	23	23	112
260	36	276	595
300	15	330	121

- At low speeds (0-30 m\s): the deformation is toward Y-axis, this is called Directional Deformation
  For example:
  At (2 m\s)

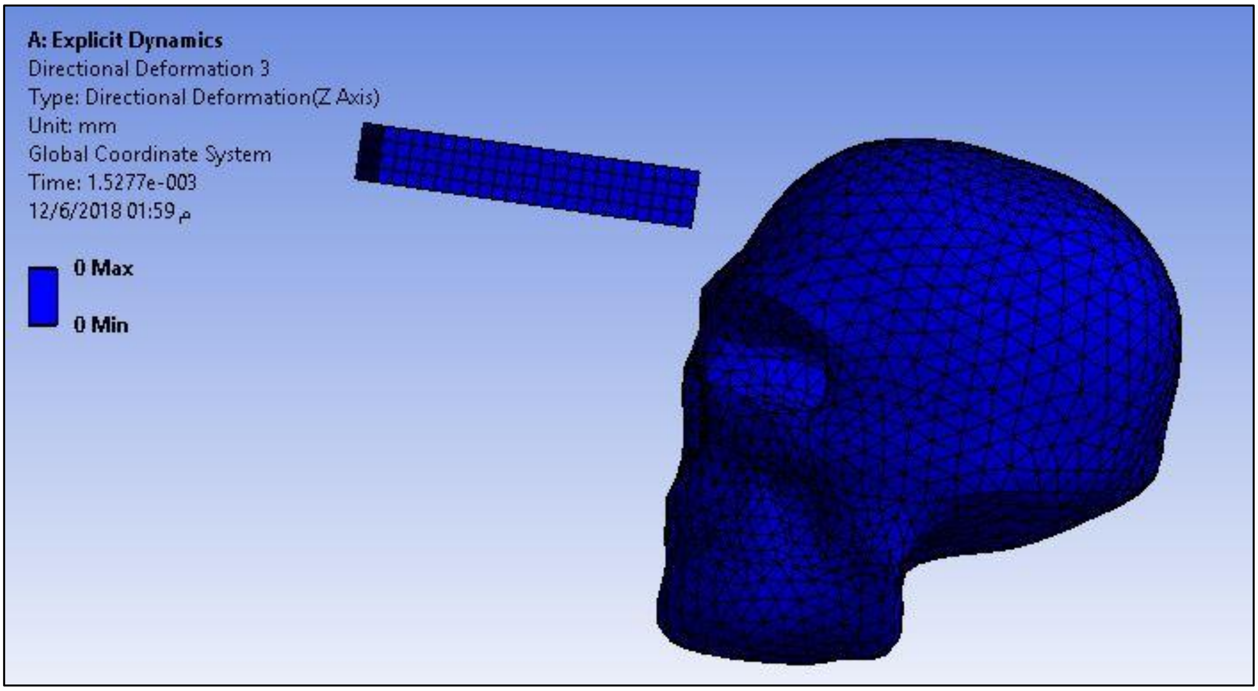
The Direction of deformation at X-axis as shown:



The Direction of deformation at Y-axis



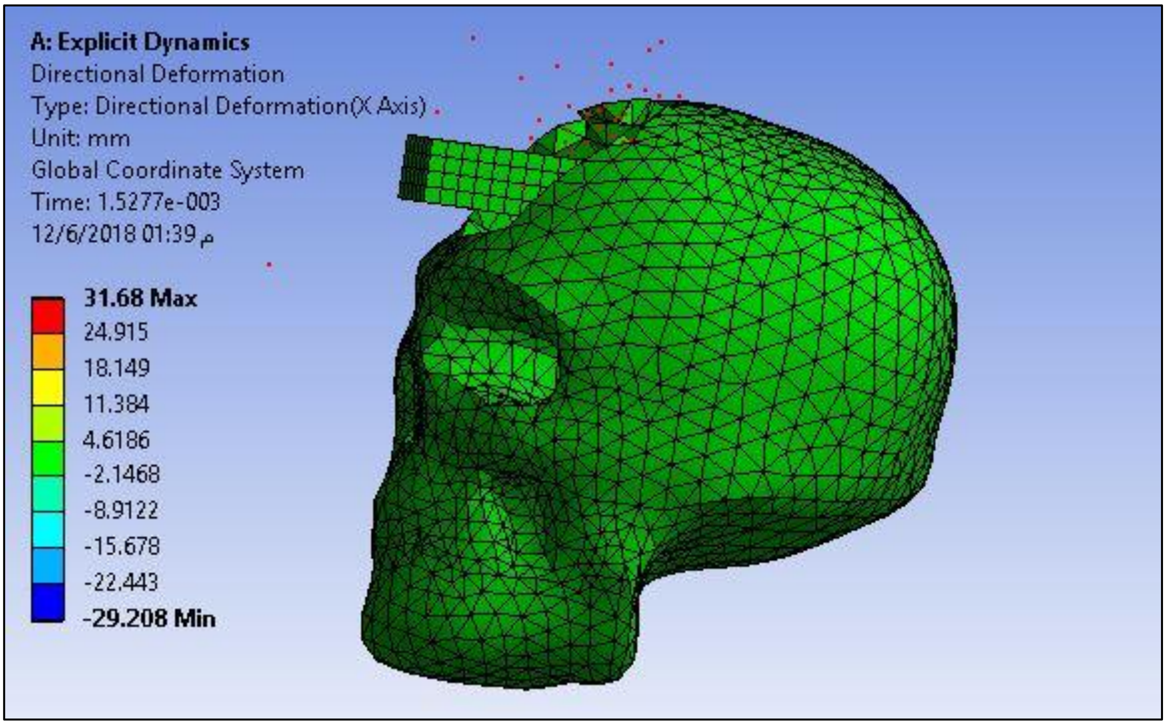
The Direction of deformation at Z-axis



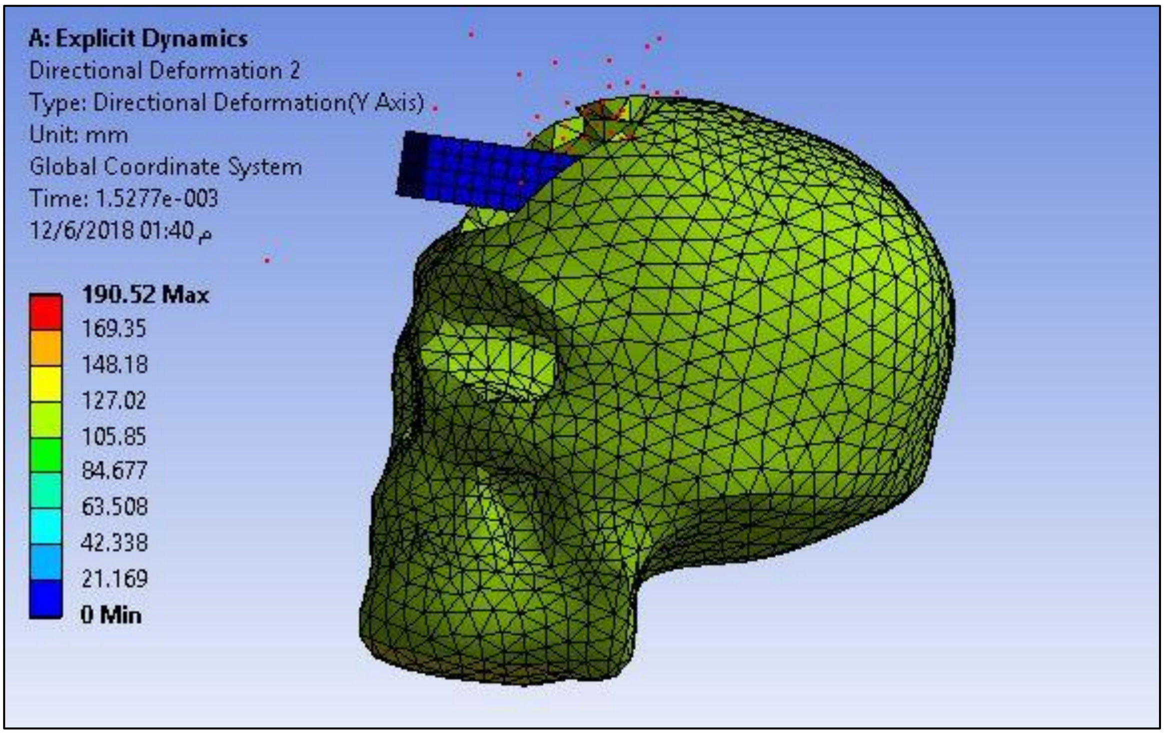
- At higher speeds: The highest deformation is towards Y-axis and at X, Z axiss is less, This is called multidirectional.

For example: At (130 m\s)

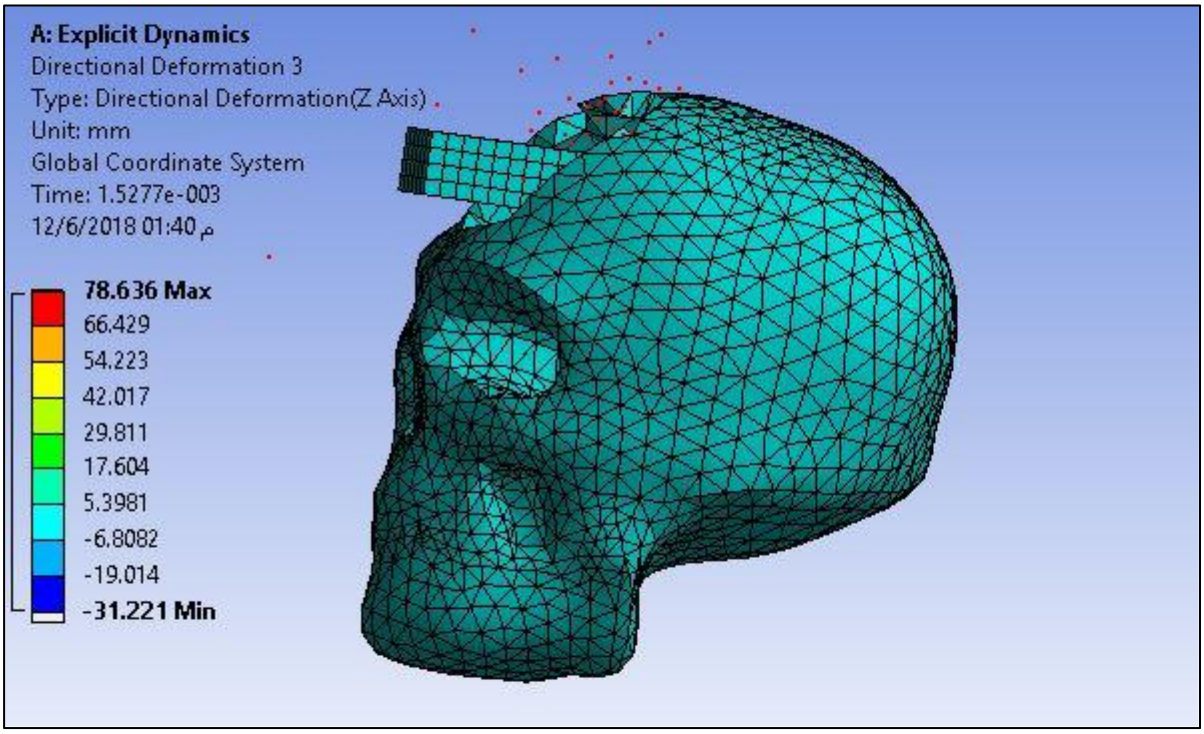
The Direction of deformation at X-axis as shown:



The Direction of deformation at Y-axis as shown:



The Direction of deformation at Z-axis as shown:



5.3 Recommendation:

1. Create a path extending from the front area to the posterior region of the skull
2. Exposing the skull to load on the front area at different angels.

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