



**STUDY OF STRESS ON A ROTARY HARROW TOOTH
DURING VARIOUS WORK PHASES IN THE GROUND.**

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Abstract

Technologies and computer software available currently allow to design and solve very complicated mechanical problems. In this study two types of FEM studies have been carried out, the first is the FEM analysis of three types of blades interaction with sandy clay soil using SOLIDWORKS and ANSYS software, and the second study is the FEM of the whole wheel containing two identical blades rotating inside 4 different types of soil which are the dry sand, sandy clay, sandy gravel, and silty sand. All 3D designs were carried out using SOLIDWORKS, note that the three types of blades are familiar and used in most of the agricultural machines' companies which are the bended, flexed, and vertical blades. After designing the 3D models got inserted into ANSYS to start the analysis. After inserting all necessary conditions and applying the suitable mesh the results gotten from the first analysis shows that the minimum stress occurred on the flexed blade with a good soil deformation, after that the flexed blade were chosen to be attached to the entire wheel rotating in different types of soil, the results obtained from the second analysis were the reaction forces applied from each type of soil on the wheel of the harrow.

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Chapter 1

1 Introduction.

1.1 Agricultural harrows.

In agriculture a harrow is an implement for dividing and smoothing out the surface of the soil. The purpose of harrowing is to break up the lumps of soil and to provide a finer finish, a good tilth or soil structure that is suitable for seedbed use. Coarser harrowing may likewise be utilized to evacuate weeds and to cover seed after sowing. Harrows vary from cultivators in that they bother the entire surface of the dirt, for example, to set up a seedbed, rather than aggravating just restricted trails that skirt trim lines (to slaughter weeds).

There are four general kinds of harrows: circle harrows, tine harrows (counting spring-tooth harrows, drag harrows, and spike harrows), chain harrows, and chain-plate harrows. Harrows were initially drawn by draft creatures, for example, stallions, donkeys, or bulls, or in a few times and places by unskilled workers. In present day hone they are quite often tractor-mounted actualizes, either trailed after the tractor by a drawbar or mounted on the three-point hitch.

A cutting-edge advancement of the conventional harrow is the rotary power harrow, frequently just called a power harrow.

1.2 types of harrows.

I am just going to cover two or three the fundamental kinds of harrows here. We will discuss spring harrows, roller harrows, chain harrows and plate harrows.

Spring Harrows:

This kind of harrow is a more established style. It isn't utilized all the time. It utilizes adaptable iron teeth that mounted in columns to relax up the dirt to set it up for planting. This kind of execute is commonly balanced by hand. Rows. [1]



Roller Harrow:

We utilize roller harrows to get ready soil for seed planting. They should squash the dirt and separate any pieces of soil. Generally, this kind of harrows comes after a spring harrow. [1]



Chain Harrow:

We use chain harrows to aerate the soil, lift matter off the ground, and to help spread out matter in the field. Sometimes they to cover seed and loosen packed soil.

Chain harrow are commonly used on baseball diamonds and in landscaping. They can also be used to break up chunks of fertilizer. [1]



Disc Harrows:

They are utilized to plan fields by either hacking up weeds or remaining product material. The plates are sunken to separate the dirt in the wake of furrowing. Plate harrows regularly utilize a 'x' design with a specific end goal to enhance how the dirt is spread out. They are more forceful than spring or tine harrows. [1]

**Power harrow (our case of study):**

A rotary power harrow, or essentially control harrow, has various arrangements of vertical tines. Each arrangement of tines is pivoted on a vertical hub and tills the dirt on a level plane. The outcome is that, not at all like a revolving tiller, soil layers are not turned over or upset, which is

valuable in keeping torpid weed seeds from being conveyed to the surface, and there is no even cutting of the subsurface soil that can prompt hardpan arrangement.



1.3 About rotary power harrow.

The rotating power harrow is an excellent connection for getting ready seed beds before planting. It includes several sets of tines, which each rotate about a vertical axis (not horizontal like a rear tine tiller). Thus, they stir the soil in a motion similar to that of an eggbeater.

The even mixing activity of the harrow abstains from exasperating soil layers and leaves soil structure flawless, dissimilar to the rototiller, which blends topsoil with subsoil. This is more beneficial for your dirt since it doesn't upset the dirt microbiology to such an extent. The flat activity additionally lessens weed seed germination by not getting new weed seeds as of now the dirt to the surface. Moreover, soil compaction is less, keeping the development of hardpan.

The power harrow skims freely of the flat hub of the tractor, enabling it to take after and level out harsh landscape.



1.4 Power harrow main components.

BOX SHAPED WELDED FRAME:

This sort of edge guarantees the most extreme inflexibility and ensures the ideal arrangement of all the transmission parts in every single working condition.

TRANSMISSION: From the p.t.o. Main transmission.

cardan shaft with cam limiter. reduction gearbox with manual change spur gears in oil bath, straight-toothed crown-pinion unit for the transmission shaft drive, with rotation speed variable from 212 to 437 rpm, based on the gear ratio chosen and the selected speed of the p.t.o. of the tractor.

Transmission to the implements: straight-toothed spur gears.

Rigid fixed blades.

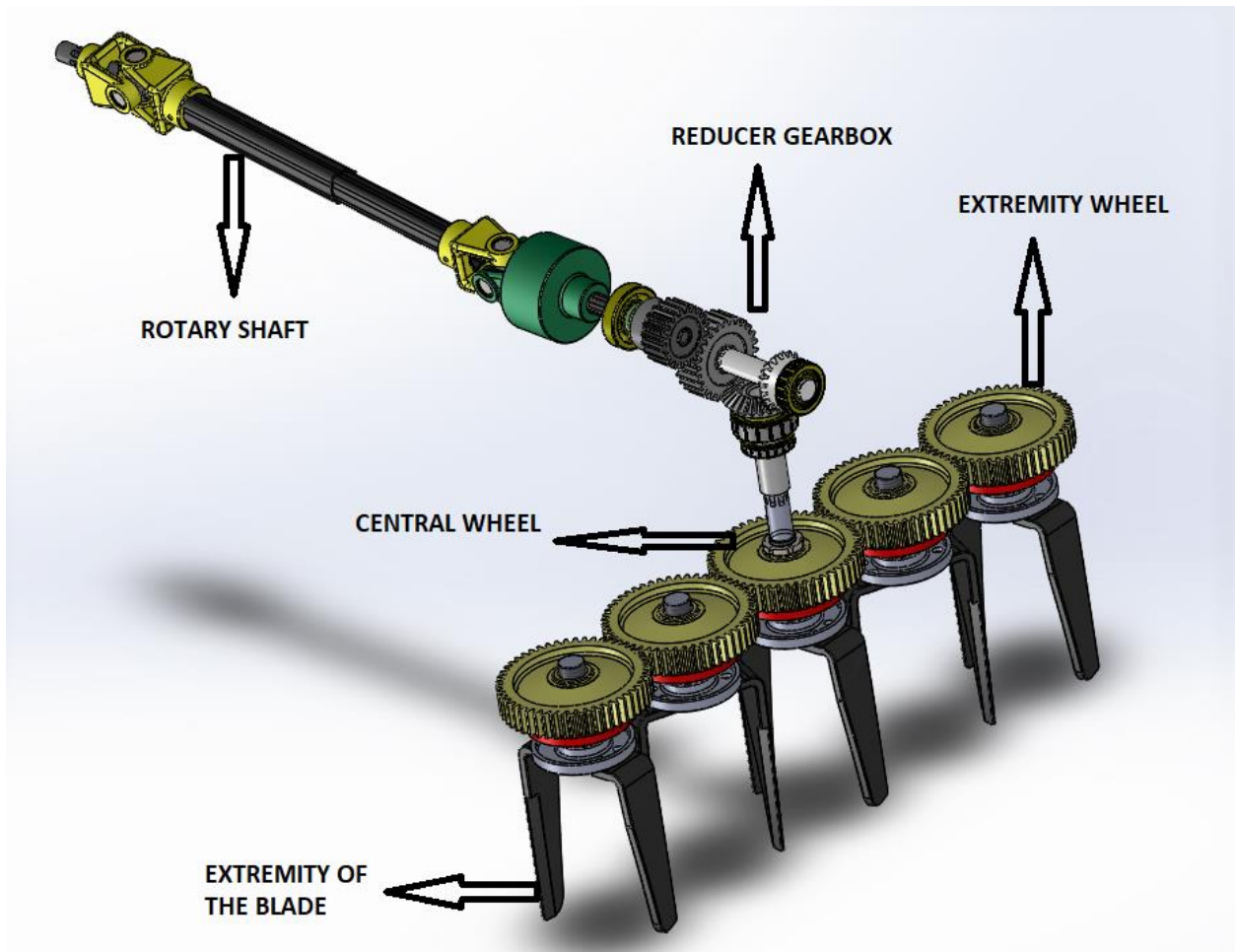


Figure 1 Entire part of the power harrow

1.5 Project concentration.

In this research we are concentrating on the blade section and its interaction with different types of soil, finding reaction effects of soils on variable blades such as stress, reaction forces, and deformation of soil done by the blade.

Finding these results is somehow tough since it needs many experiments and equipments in order to do the analysis, but fortunately nowadays its possible to do all this analysis on the computer, thanks to the advanced software exists.

In our work we are using **Ansys** software which is capable for doing dynamic analysis for any interaction between two types of materials. But lets first introduce some information about the blade.

The present rotating blade is made of two tines that can easily be changed in case of failure, the tines are made of a hard steel with 33 cm length and 1.6 cm thickness mounted to rotors with cemented gears with taper roller bearing, and able to perform from 5 to 20 cm depth and 300 to 400 cm width.

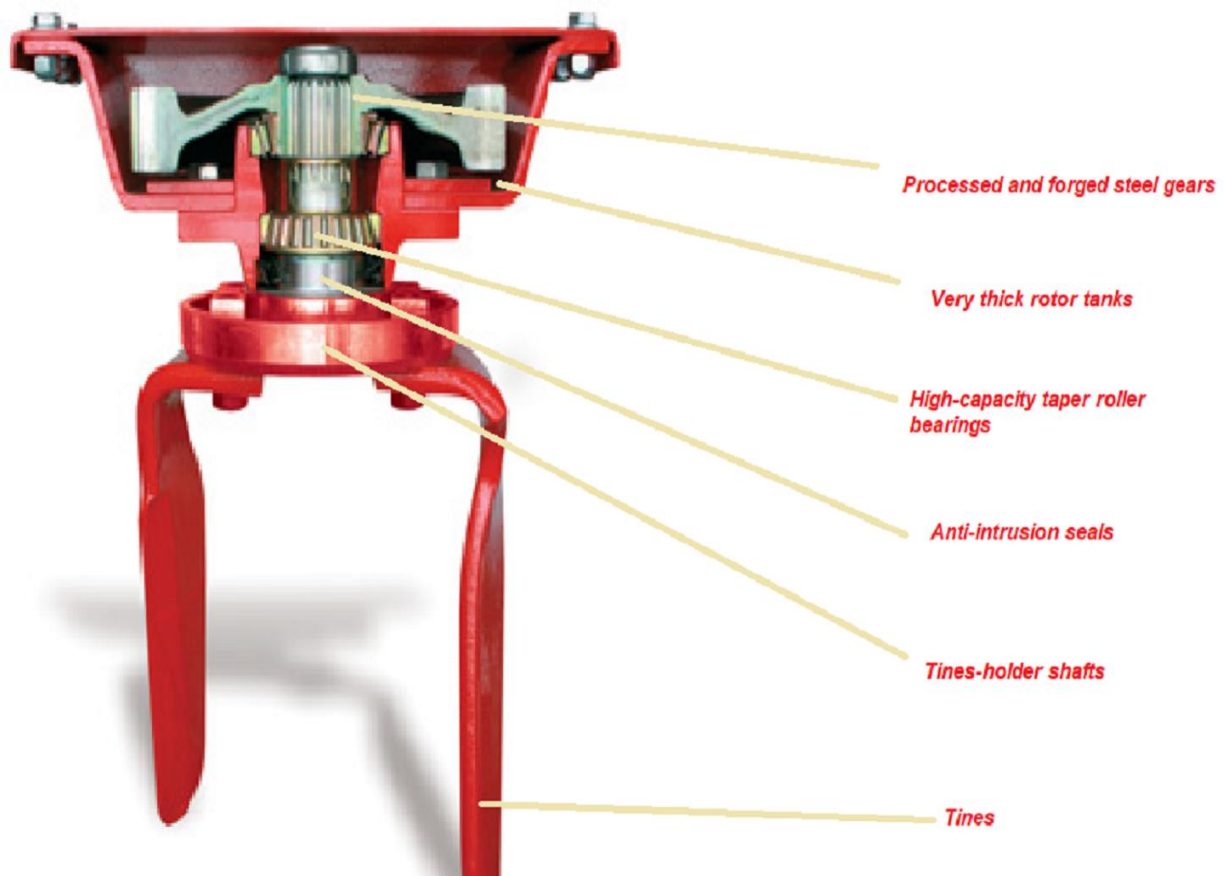


Figure 2 blade section.

Tines:

The tines of some power harrows take a lot of time to be removed from the rotors and the

disassembly is rather complicated. To solve this problem, Frandent has invented the new patented system Rapident: in two simple operations and few seconds you can loose and extract the tines.

A great advantage: the tines can be removed and mounted from the

center of the rotor rather than from the exterior. No bolts required. Tines

fit perfectly in their seating and during the tillage, they are pushed in their housing by the centrifugal force. An ingenious throttle block fastens the tines preventing them from coming out of their housing. A particular treatment ensures high wear resistance materials.

Easy reversal of the tines that allow to choose the working angle:

Thanks to the possibility of reversing right/left tines so simply, you can select the most suitable working angle at any time: aggressive for hard surfaces or for the weeding; classic for standard work.

Save time and work in comfortable conditions:

Rapident system allows you to save your time, increase your profit and improve your working conditions. Moreover, the value of your power harrow will increase in case you decide to sell it. The assembly at different angles between the rotors allows great speed without vibrations and working in very strong

and difficult soils.



Figure 3 tooth assembly



Figure 4 tooth disassembly

1.6 project description and goals.

In this project our concentration is on the blades of the rotary harrow, our goal is evaluating the forces and stresses exerted on the blades during rotation in different types of soil, using different types of blades with different geometry, in addition we are able also to measure the deformation of the soil surface. Those values that we will get from the analysis will be useful for later evaluation of power and energy in order to develop the performance of the harrow getting the highest working speed with the lowest power and fuel consumption, also increasing the life of the blades.

For this purpose we are using the **FINITE ELEMENTS METHOD (FEM)** running on Ansys software. Since we don't have a concentrated point of friction or pressure forces we need to use **explicit dynamics** analysis system. The main interference parameters in the analysis were the directional velocity of the blade calculated by the addition of the velocity of the tractor and the converting of rotational velocity to linear, the elastic parameters of both soil and blade (elastic modulus, Poisson's ratio, shear modulus, and bulk modulus), and the compaction characteristics of the sand in wet, dry, and fully saturated conditions

Chapter 2

2 Materials and Methods

2.1 About (FEM) explicit dynamics Ansys.

As mentioned before nowadays, we can get experimental results using computer software, one of that software is Ansys that allow us to various types of analysis, the suitable analysis for our case is the EXPLICIT DYNAMICS analysis system that is used for nonlinear, transient dynamic forces.

ANSYS Explicit Dynamics is a transient unequivocal elements Workbench application that can play out an assortment of building reproductions, including the displaying of nonlinear dynamics of solids, liquids, gases and their association. Moreover, the Explicit Dynamics (LS-DYNA Export) framework is accessible to send out the model in (LS-DYNA .k) document arrange for resulting investigation with the LS-DYNA solver.

A common reproduction comprises of setting up the model, interactions and the applied loads, explaining the model's nonlinear powerful reaction after some time for the heaps and communications, at that point looking at the subtle elements of the reaction with an assortment of accessible instruments.

The Explicit Dynamics application has objects masterminded in a tree structure that guide you through the distinctive strides of a recreation. By extending the articles, you uncover the points of interest related with the protest, and you can utilize the comparing apparatuses and particular tables to play out that piece of the reproduction. Items are utilized, for instance, to characterize ecological conditions, for example, contact surfaces and loadings, and to characterize the sorts of results you need to have accessible for survey.

The explicit dynamics has been created for the simulation of nonlinear structural mechanics applications and works in various cases such as:

- Stress wave propagation.

- low and very high velocity.

-High frequency dynamic response.

-Rigid and flexible bodies, etc.....

Explicit dynamics analysis is based on the solution of differential equations expressing the conservation of mass, momentum, and energy in Lagrangian coordinates. In addition to the boundary conditions applied the complete solution will be defined.

-Density with time equation, which is determined from the current volume and its initial mass.

$$\frac{\rho_0 V_0}{V} = \frac{m}{V}$$

-Partial differential equations: conservation of momentum that present the acceleration to stress tensor σ_{ij} .

$$\begin{aligned}\rho \ddot{x} &= b_x + \frac{\partial \sigma_{xx}}{\partial x} + \frac{\partial \sigma_{xy}}{\partial y} + \frac{\partial \sigma_{xz}}{\partial z} \\ \rho \ddot{y} &= b_y + \frac{\partial \sigma_{yx}}{\partial x} + \frac{\partial \sigma_{yy}}{\partial y} + \frac{\partial \sigma_{yz}}{\partial z} \\ \rho \ddot{z} &= b_z + \frac{\partial \sigma_{zx}}{\partial x} + \frac{\partial \sigma_{zy}}{\partial y} + \frac{\partial \sigma_{zz}}{\partial z}\end{aligned}$$

-conservation of energy equation:

$$\dot{e} = \frac{1}{\rho} (\sigma_{xx} \dot{\epsilon}_{xx} + \sigma_{yy} \dot{\epsilon}_{yy} + \sigma_{zz} \dot{\epsilon}_{zz} + 2\sigma_{xy} \dot{\epsilon}_{xy} + 2\sigma_{yz} \dot{\epsilon}_{yz} + 2\sigma_{zx} \dot{\epsilon}_{zx})$$

-For each time step, these equations are solved explicitly for each element in the model, based on input values at the end of the previous time step

-Only mass and momentum conservation are enforced. However, in well posed explicit simulations, mass, momentum and energy should be conserved. Energy conservation is constantly monitored for feedback on the quality of the solution (as opposed to convergent tolerances in implicit transient dynamics).

-nodal forces equation:

$$\ddot{x}_i = \frac{F_i}{m} + b_i$$

where x_i are the components of nodal acceleration ($i=1,2,3$), F_i are the forces acting on the nodes, b_i are the components of body acceleration and m is the mass of the node.

-With the accelerations at time $n - 1/2$ determined, the velocities at time $n + 1/2$ are found from.

$$\dot{x}_i^{n+1/2} = \dot{x}_i^{n-1/2} + \ddot{x}_i^n \Delta t^n$$

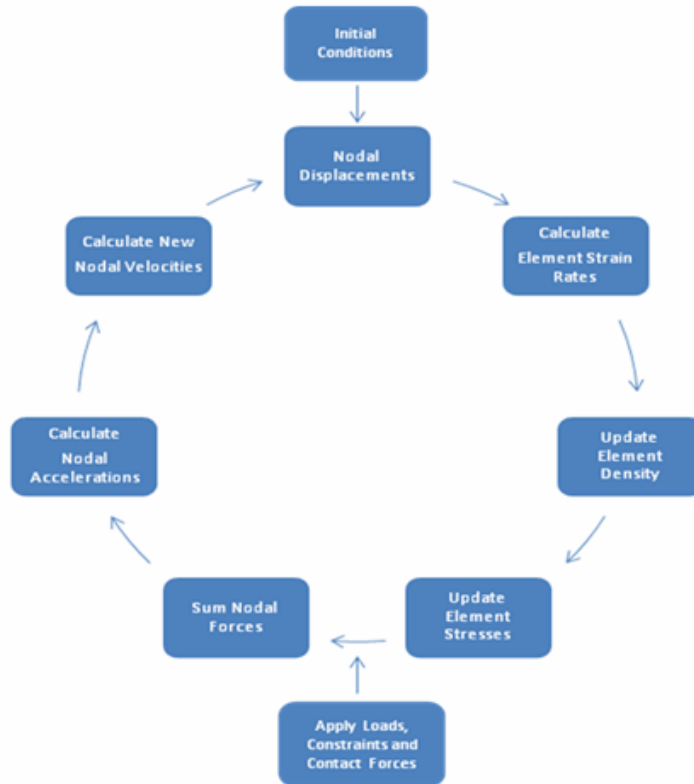
-The positions are updated to time $n+1$ by integrating the velocities.

$$x_i^{n+1} = x_i^n + \dot{x}_i^{n+1/2} \Delta t^{n+1/2}$$

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 since the equations are uncoupled.
- No inversion of the stiffness matrix is required. All nonlinearities (including contact) are included in the internal force vector.

The solution strategy in explicit dynamics:



- 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. [2]

2.2 Materials properties and parameters used.

The main components in our analysis are the harrow's blades and the soil. In this section we are going to describe the parameters used in order to define the material used for the blade and each type of soil in order to be readable by Ansys (explicit dynamics) system.

In finite element analysis the material properties assigned to a part indicates the response of this part during the analysis.

Materials are mainly divided into two cases, linear or nonlinear.

Linear materials properties can be constant, isotropic or orthotropic, while nonlinear material properties are usually tabular data, like plastic or hyper-elastic data. [2]

2.2.1 Blade properties.

The material defined for the three types of blade was the structural steel defined in Ansys engineering data library, its main parameters are the density, the isotropic elasticity, and the specific heat as mentioned in table below.

Parameter	Value	Unit
Density	7850	Kg/m ³
Young modulus	200000000000	Pa
Poisson ratio	0.3	
Bulk modulus	166666666666.667	Pa
Shear modulus	76923076923.0769	Pa
Specific heat	434	J kg ⁻¹ C ⁻¹

We have mentioned above the most effective parameters in the explicit dynamics' analysis knowing that there are other parameters that define the strength of our steel, but it's important to differentiate between them since those parameters are supported in static structural analysis and not in explicit dynamics one as in our case. Even if those parameters do not affect our results in the analysis it's still important to mention them to understand well the behaviour of the steel attached to our harrow. Let's look on some of these parameters in the table below.

parameter	value	Unit
Isotropic Thermal Conductivity	60.5	W/ m°C
Isotropic Resistivity	1.7e-007	ohm m
Compressive Ultimate Strength	0	pa
Compressive Yield Strength	250000000	Pa
Tensile Yield Strength	250000000	pa
Tensile Ultimate Strength	460000000	pa
Strength Coefficient	920000000	pa
Cyclic Strength Coefficient	1000000000	pa
Relative Permeability	10000	

2.2.2 Soil properties.

The value of reaction force acting on the blade is affected by the physical and mechanical properties of the soil. Before talking about the parameters used in our analysis the soil's physical and dynamic properties should be discussed in order to understand the complexity of soil non-linear behaviour.

Soil physical properties

Soil physical properties include soil texture or structure that is associated with soil water content. Soil texture is one of the most important factors that may change the mechanical behaviour and strength of soil. Soil texture classifies soils in several groups such as gravel, sand, silt and clay based on the size of individual grains. Based on the “US Department of Agriculture” (USDA) standard, soil particles with diameter between 2-75mm are classified as gravel; consequently, particles with finer diameters between 0.05-2mm are considered as sand and between 0.002-0.05mm considered as silt. The last group is clay in which the particle’s diameters are less than 0.002mm. Based on [3], most soils do not fall in one specific category that is mentioned above and may be a mixture of two or more groups. Soils are classified based on the percentage of each category. It should be mentioned that by changing the soil texture, soil behaviour will change, even though the mechanical condition stays same. Another parameter that affects mechanical behaviour of soil is its water content which is the amount of water in the pore space between soil particles.

Soil dynamic properties.

The dynamic properties of the soil are the properties during the motion of the soil making it so difficult to be measured because of its nonlinearity. Most of studies assume the dynamic properties of soil is constant because of the different strength of the soil in different conditions. [4]

Soil cohesion.

Soil cohesion is the bonding force between the particles of the soil, its measured in pascal and not related to strength of the soil. physical properties such as soil texture and soil water content can affect cohesion which results from electrostatic bonds between clay and silt particles. [5]

Internal friction angle.

Angle of internal friction (ϕ) is representing the existence of friction force between soil particles. Based on this definition, part of tillage energy is used to break the cohesive bonds between particles and their rolling and sliding on each other. Same as soil cohesion, internal friction angle is affected by physical properties such as soil texture and soil water content. As concluded, normally coarse-grained soils (high sand fraction) exhibit higher friction angles. Thus, sandy soils are considered as frictional soils because of their larger angle of internal friction in comparison with the clays. Internal friction angle mostly varied from 25 for moist and fine soil particles to about 45o for dry, dense, coarse soil particles. [5]

Soil shear strength.

soil strength is the capability of soil to sustain an applied force. However, soil strength may be affected by soil texture combination, but soil water content and bulk density are the most effective factors on soil strength changes. By expanding the volume of soil, the density of particles or bulk density decreases and subsequently strength will decrease. During tillage, soil can fail based on several effects such as shear, compression and tension. The shear effect on failure zone is higher than the other two. For years, many research works have been carried out in this field, but finally Coulomb proposed a general form of shear strength as shown below which is known as Mohr-Coulomb criteria.

$$\tau_{\max} = c + \sigma_n \tan\phi .$$

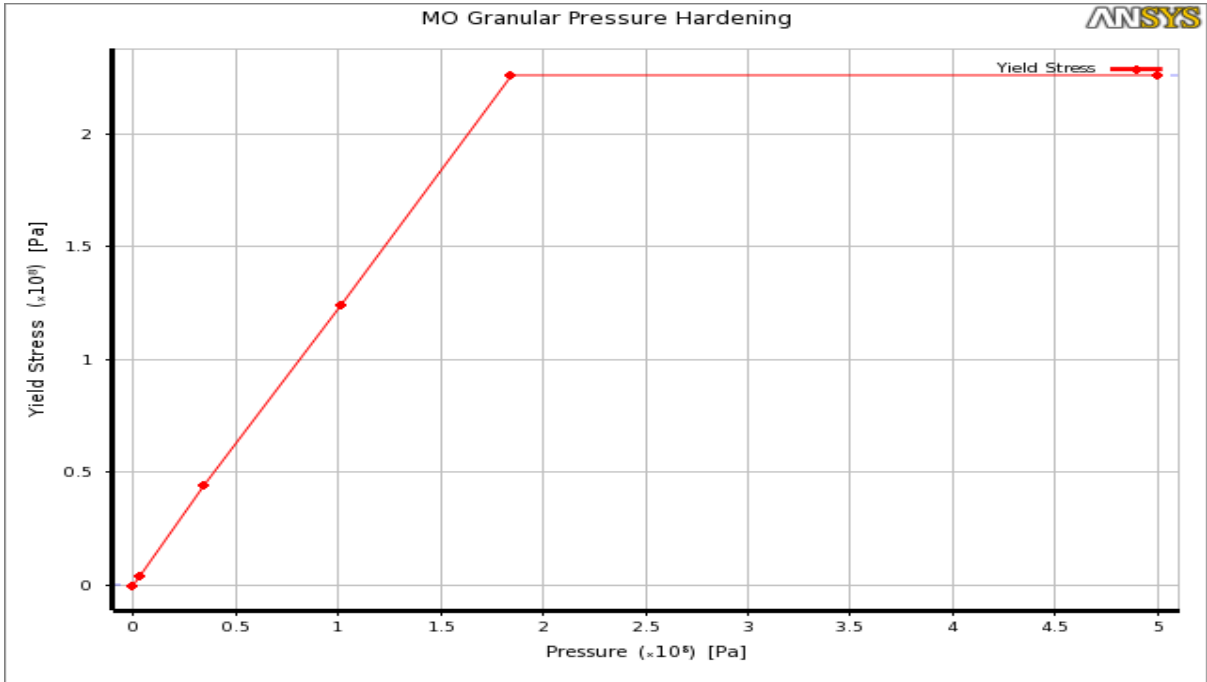
This criterion is used with triaxial test (shear strength test) to determine soil cohesion (c) and internal friction angle (ϕ). By drawing Mohr's circles based on triaxial test results on cylindrical soil sample and soil-failure line (a line tangent to Mohr's circles), soil cohesion (c) and internal friction angle of soil (ϕ) are determined. Cohesion is the intercept of the soil-failure line on the shear stress line and internal friction angle is the slope of the soil failure line. [4]

2.2.2.1 Soil properties and parameters inserted in Ansys.

As we know soil is a material formed of separated particles with or without cohesion forces applied between each other. Thus, soil is considered as brittle/granular material and should be presented in Ansys library by inserting parameters related to Drucker-Prager or Johnson-Holmquist model. Since soil is a granular material the suitable model that should be applied in order to design a soil model in Ansys is **Mo granular** which is based on Drucker-Prager model that takes into account the effects associated to the granular materials, in which it represents the pressure hardening, density hardening, and the variation of shear modulus with respect to density. The input data to be inserted since soil is non-linear material are given as tabular data made of a series of constants that are interpreted when they are used. In this case we have three tabular data the first one is the yield stress versus pressure curve which represents the pressure hardening, the second one is yield stress in the variation of density which represents the density hardening, and the last one which defines the unload or reload slope is the shear modulus versus density. In Ansys explicit dynamics material library the only type of soil defined is the dry sand in which the three curves represented by the tabular data are given from experimental results already done. However, the data for other types of soil need to be used in the analysis must be inserted manually using another experimental result defining them. Since our types of soils in analysis are all sandy so the Mo granular data is assumed to be the one for the sand but considering the wetness of the soil which is not dry in fields. So, in total two Mo granular tabular data must be defined one is already defined which is the dry sand, and the second one representing the wet soil or half saturated one [6]. Both are shown in the tables and their output curves below. [6]

Pressure (Pa)	Yield Stress (Pa)
0	0
3.401e+006	4.235e+006
3.4898e+007	4.4695e+007

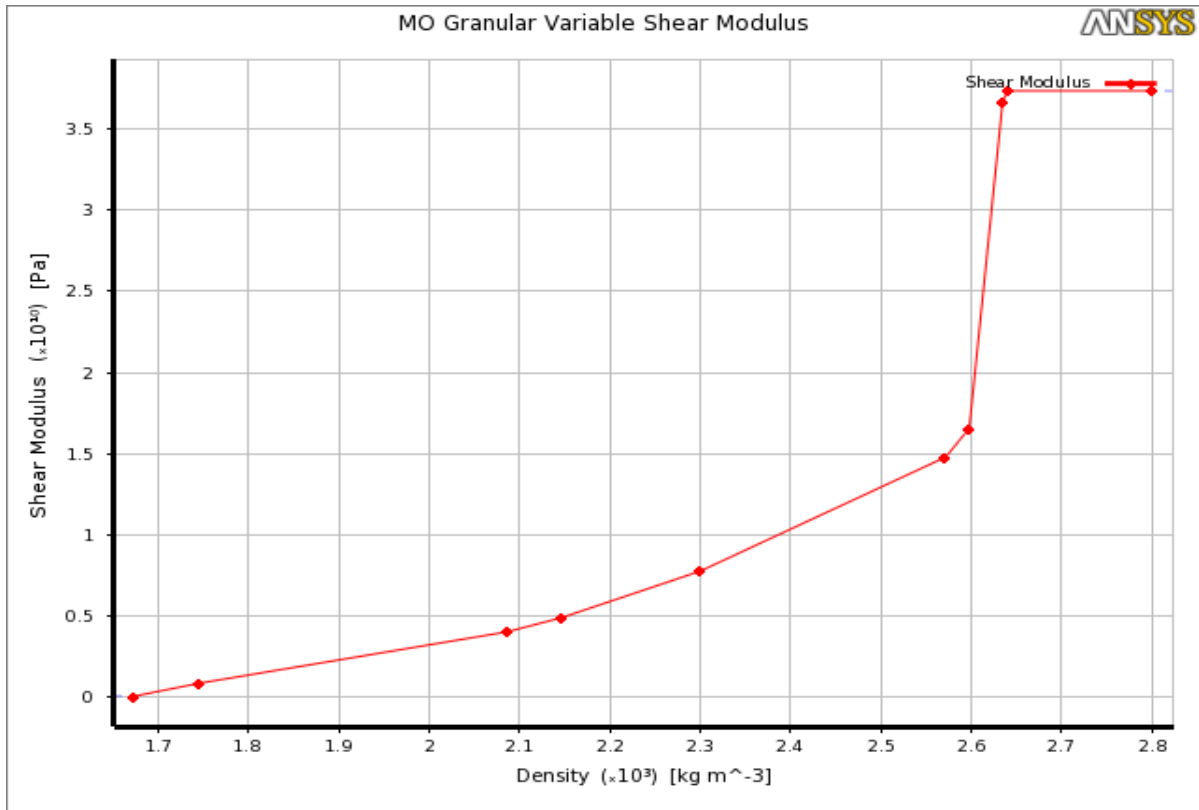
1.0132e+008	1.2404e+008
1.8465e+008	2.26e+008
5.e+008	2.26e+008



Density kg m ⁻³	Yield Stress Pa
1674	0
1745.7	0
2086.3	0
2146.8	0
2300	0
2572	0
2598	0
2635	0

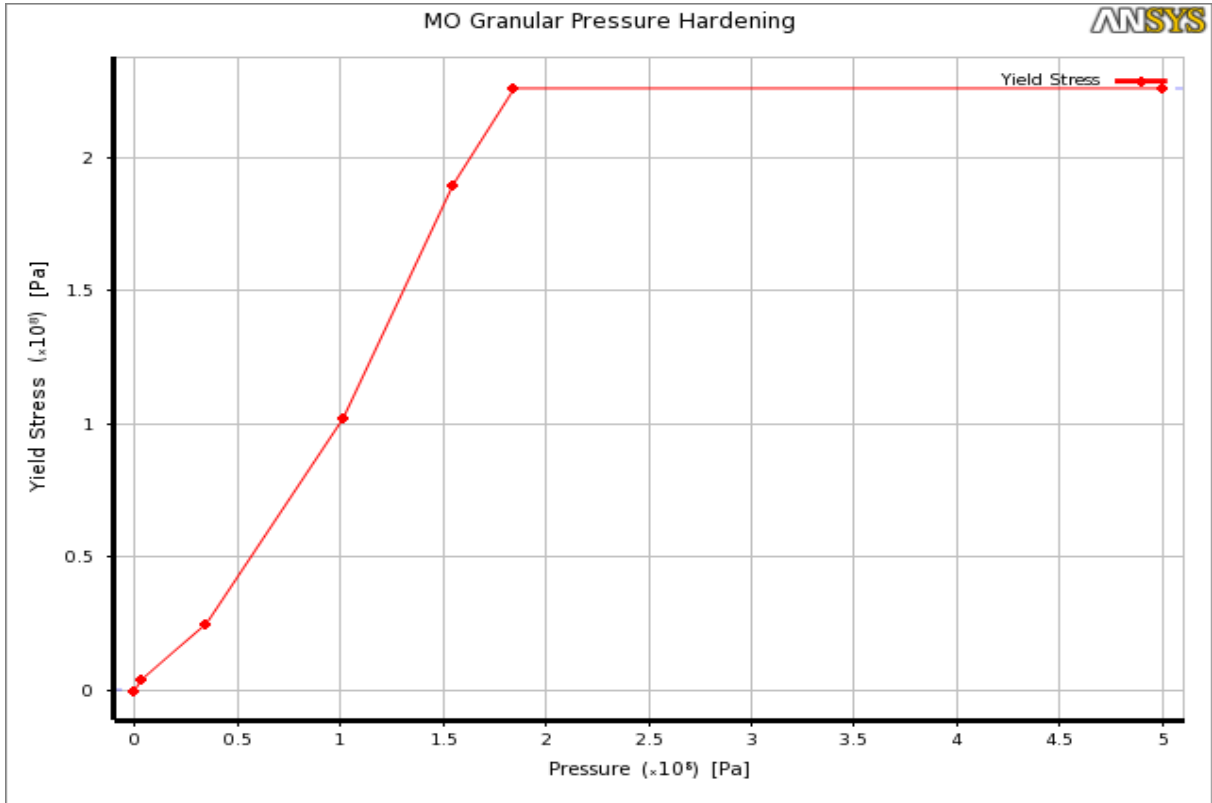
2641	0
2800	0

Density kg m ⁻³	Shear Modulus Pa
1674	7.69e+007
1745.7	8.694e+008
2086.3	4.0317e+009
2146.8	4.9069e+009
2300	7.769e+009
2572	1.4801e+010
2598	1.6571e+010
2635	3.6718e+010
2641	3.7347e+010
2800	3.7347e+010



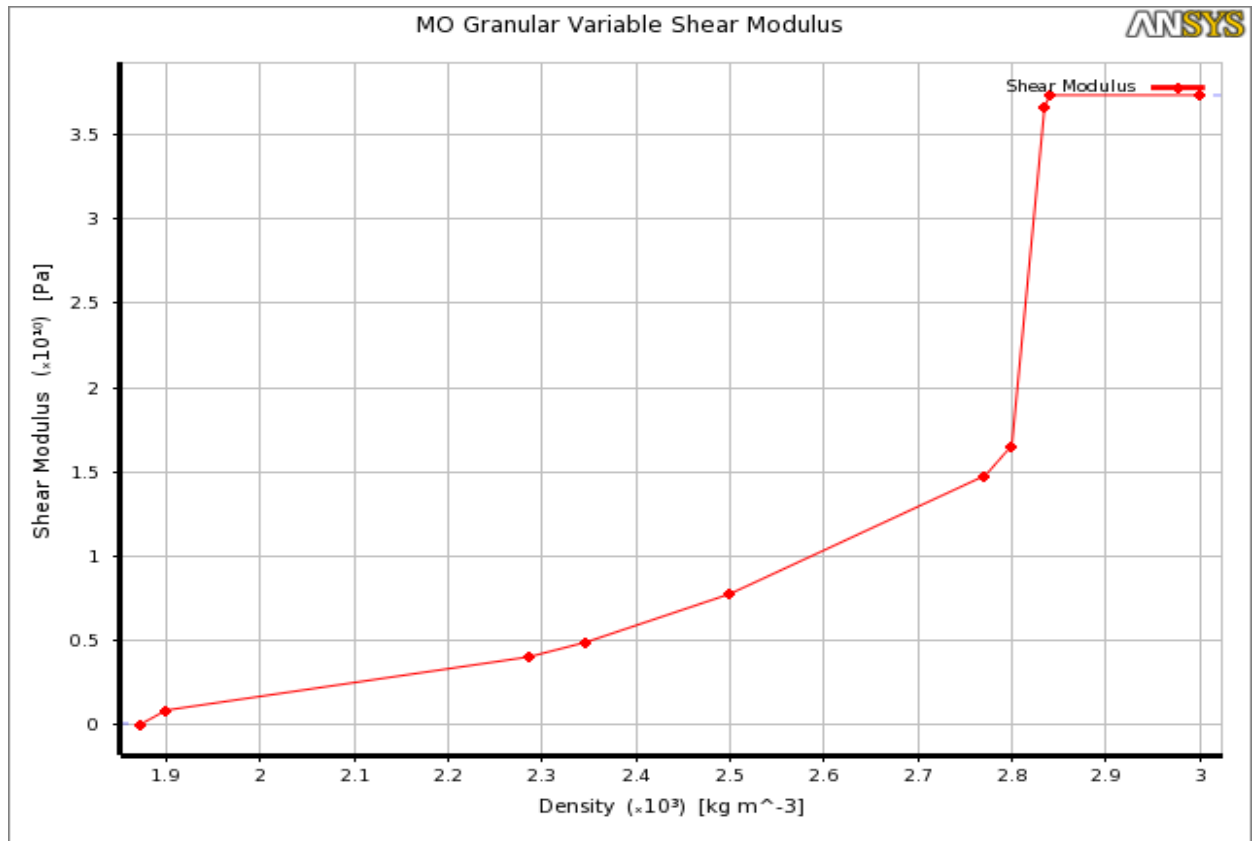
The data above was related to the dry sand with no or negligible cohesion force between the grains. The MO granular data of the wet soil or half saturated one that is assumed to present other types of soil used in our analysis which are the sandy clay, silty sand, and sandy gravel are listed down in tables and curves below. [6]

Pressure Pa	Yield Stress Pa
0	0
3.401e+006	4.e+006
3.4898e+007	2.5e+007
1.0132e+008	1.02e+008
1.55e+008	1.9e+008
1.8465e+008	2.26e+008
5.e+008	2.26e+008



Density kg m ⁻³	Yield Stress Pa
1874	0
1900	0
2286	0
2347	0
2500	0
2772	0
2800	0
2835	0
2841	0
3000	0

Density kg m ⁻³	Shear Modulus Pa
1874	7.69e+007
1900	8.694e+008
2286	4.0317e+009
2347	4.9069e+009
2500	7.769e+009
2772	1.4801e+010
2800	1.6571e+010
2835	3.6718e+010
2841	3.7347e+010
3000	3.7347e+010



The MO granular data above was to define the material strength model under highly dynamic loading that describes the non-linear elastic-plastic response of the soil, however, in the dynamic analysis that is not enough for the simulation to go on since the modelling of the response to dynamic loading is composed of two main components in addition to the material strength model which are the equation of state (EOS), and the material failure model .

The equation of state is the component that describes the hydrodynamic response of the material as a primary response, in liquids and gases the dynamics response assumed to be hydrodynamic with pressure varies as function of density and internal energy, while in solids the response is assumed to be hydrodynamic at high deformation rates when the hydrodynamic pressure is more much greater than the yield stress of the material.

The material failure is the failure of the solids under extreme loading conditions which leads to the crush or crack of the material.

In explicit dynamics engineering data properties the main material effects that determine the material behaviour for the soil are:

Elasticity.

Shock Effects.

Porous Compaction.

Plasticity.

Pressure Dependent Plasticity.

Shear Damage/Fracture.

Tensile Damage/Fracture.

The most accurate equation of state for defining non-linear materials as soil is the porosity compaction non-linear equation of state. The compaction EOS Non-Linear property is an extension of the compaction EOS linear one that represents the non-linear unloading of the porous material. The response with the compaction Non-linear equation of state is represented via:

- A plastic compaction path defined as a piecewise linear function of pressure versus density.

- The non-linear unloading defined by means of a piecewise curve of bulk modulus versus density.

Another good property is the compaction EOS linear property that can define the response of porous materials but less accurate than the Non-linear EOS. It represents the response of the material via:

- A plastic compaction path defined as a piecewise linear function of pressure versus density.

- The elastic unloading/reloading path defined via a piecewise linear function of sound speed versus density.

This property is based on the use of a fixed compaction path (which may be derived from static compression data, either in its original state or arbitrarily enhanced to model dynamic data) that is equivalent to using a Mie-Gruneisen equation of state with an

assumed value of zero for the Gruneisen Gamma. This ignores the pressure enhancement due to the energy absorption.

The elastic bulk stiffness of the material is defined as a piecewise linear curve of sound speed (c) versus density (ρ_0). The bulk stiffness of the material is given by:

$$K = \rho_0 c^2$$

The level of compaction in the material is given by:

$$\alpha = \frac{\rho_s}{\rho_0}$$

Initially, ρ_0 will be equal to the value defined in the density property of the material. Material property ρ_s is the solid zero pressure density of the material and corresponds to the fully compacted material density. For a porous material the initial density will be less than the solid density hence the value of α will be greater than 1.0. As compaction takes place, α will reduce to a value of 1.0 for the fully compacted state.

Both compaction linear and Non-linear equation of state are complicated since too much complicated data required to be inserted, moreover expensive and difficult experiments must be carried. Thus, EOS data found is not able to cover all porous materials including all types of soil. In ansys explicit dynamics linear compaction EOS is defined only for dry sand.

According to what mentioned before its necessary to assume some of non-defined soils as an isotropic elastic material, those properties are less accurate but its available, and many experiments done on all types of soil to get a range of elastic modulus and poison ratio. In addition, MO granular data is defined so more accuracy will be achieved.

Most of researches assume the soil materials as an isotropic elastic material within a range of elasticity described by two parameters, bulk modulus (B) and shear modulus (G). those parameters are related to the elastic modulus (young modulus) (E), and the poison ratio (ν) by the equations:

$$B = E / (3(1-2(\nu)))$$

$$G = E / (2(1+(\nu)))$$

In this analysis the values of the elastic modulus and poison ratio have been taken according to “**Obrzud R. & Truty, A.THE HARDENING SOIL MODEL - A PRACTICAL GUIDEBOOK Z Soil.PC 100701 report, revised 31.01.2012**” which provides a range of various elasticity for each type of soil for example for sandy clay the elastic modulus varies in a range between 25 and 200 Mpa, in addition to the poison ratio for each type.

In this work the worst condition which means the higher elastic modulus can the soil reach that affects the blade.

In conclusion, in addition to the MO granular properties that have been defined previously we have the compaction EOS linear for dry sand, and the isotropic elastic properties for each of sandy gravel, sandy clay, and silty sand.

First let us look on the EOS parameters for the dry sand defined by Ansys explicit dynamics material library. Note that in the EOS equation the shear modulus is not considered so the shear modulus has been defined separately for the dry sand which is **7.69e+007 Pa**. [6]

Pressure Pa	Density kg m ⁻³
0	1674
4.577e+006	1739.5
1.498e+007	1873.8
2.9151e+007	1997
5.9175e+007	2143.8
9.8098e+007	2250
1.7944e+008	2380
2.8944e+008	2485
4.502e+008	2585
6.5066e+008	2671.3

Sound speed m s ⁻¹	Density kg m ⁻³
265.2	1674
852.1	1745.6
1721.7	2086.3
1875.5	2146.8
2264.8	2300

2956.1	2572
3112.2	2598
4600	2635
4634	2641
4634	2800

With the density and the material failure that will be mentioned later with the other types of soil, sand is totally defined in the software and ready to be attached to its geometry.

As mentioned before the other types of soil were assumed to be isotropic elastic materials and their parameters chosen are shown below. [7]

Soil	Density (kg m ⁻³)	Young's Modulus (Pa)	Poisson's Ratio	Bulk Modulus (Pa)	Shear Modulus (Pa)
Sandy clay	1979	2.e+008	0.25	1.3333e+008	8.e+007
Sandy gravel	2038	3.e+008	0.3	2.5e+008	1.1538e+008
Silty sand	1843	2e+007	0.35	2.22e+007	7.4e+006
Dry sand	2641				7.69e+007

Chapter 3

3 Modelling and boundary conditions.

3.1 geometry.

The parameters defined above were defined to be applied on a suitable geometry used to describe each part in the analysis. The geometry of each part has been done by an advanced 3d software called **Solidworks** and then inserted to Ansys in order to start the analysis. The main drawings used in the analysis are the single blade, the soil box, and the rotating wheel composed of two identical blades.

3.1.1 Blade geometry.

Three types of single blades were selected and drawn for this analysis in order to distinguish which geometry is better for the work in the ground from deformation and blade life point of view. The three blades have been named flexed blade, blended blade, and vertical blade. From dimension point of view the three blades are equal so its possible for all to be assembled on the same wheels of the harrow.

On the three blades the structural steel parameters mentioned before was applied. All three blades are 0.33m length and 15mm thickness with same knife length of 0.23m and same inclination angle of 30 degrees.

The flexed blade has been twisted 20 degrees from the centre of the top face toward downward. With knife on one side and a draft of 5 degrees on the other side that starts from the level of the knife toward left till the extreme of the blade. On the extreme of the blade two fillets are made one of 32 mm radius on the side of the draft and the other of 8mm radius on the side of the knife, all other edges were being filleted with 2mm radius. The blade is shown in the figure below in three different views to be clearer.

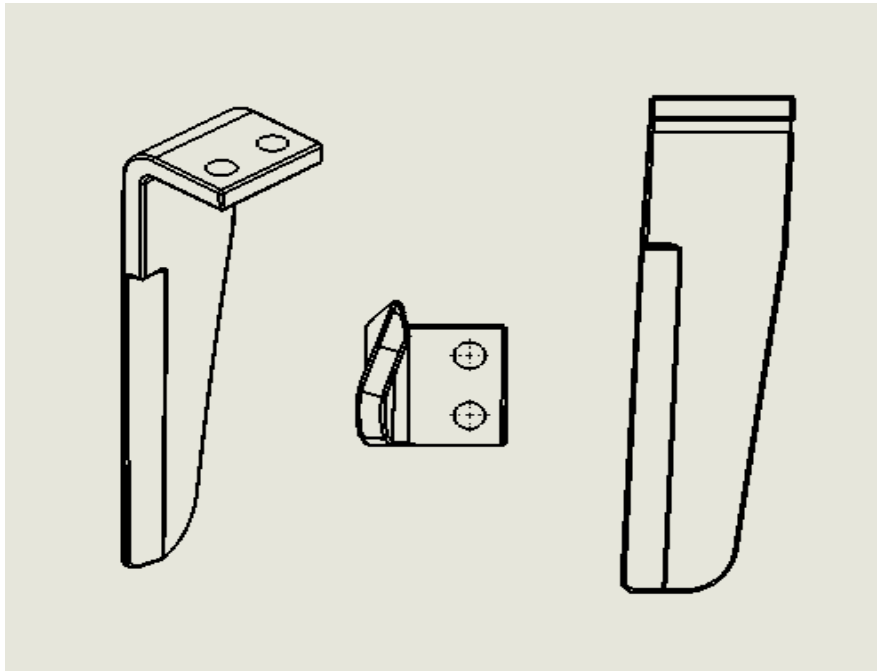


Figure 5 flexed blade

The second blade has been bended 10 degrees from the top face of the blade toward front till the extreme end. On the left side the attack knife occurs with a fillet at the end of 5mm radius and a fillet of 55 mm on the other side of the extreme end.

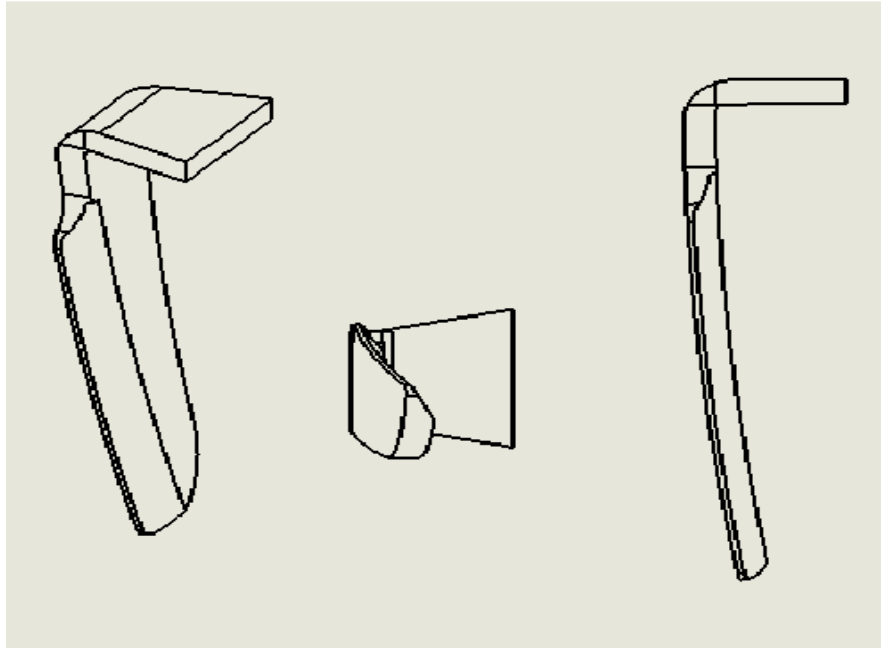


Figure 6 banded blade

The third blade was the simple vertical one with two knives on both sides and identical fillets of 8mm radius on the both extreme sides down the blade.

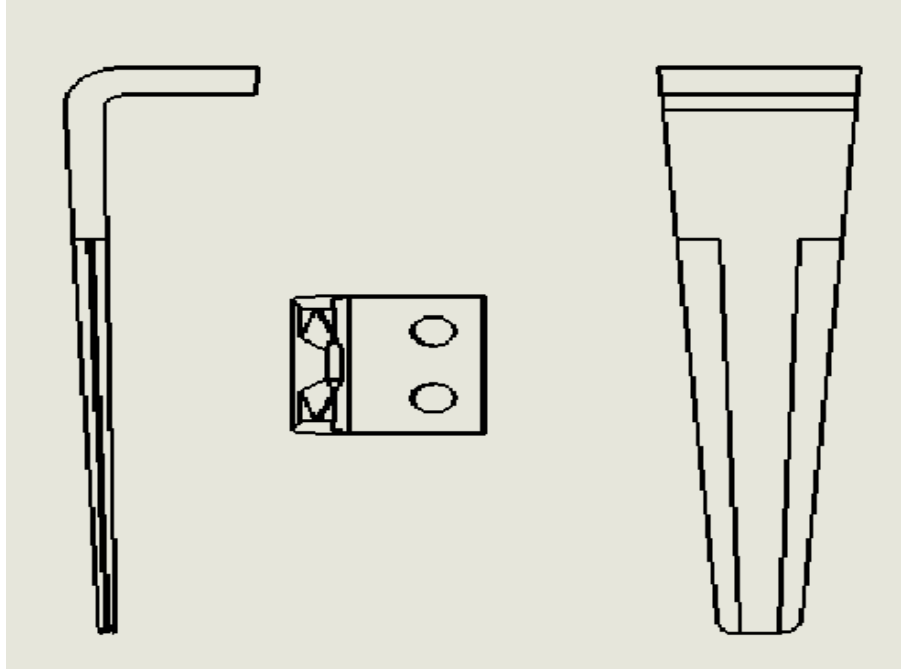


Figure 7 vertical blade

3.1.2 Soil geometry.

The geometry of the soil was considered as a simple box of a dimension on X, Y, Z coordinate system of 0.7m, 0.3m, and 0.8 m respectively. It made up of six surfaces of 0.168 m³ volume and 322.56 kg mass. Boundary condition will be added on some surfaces and parameters of each type of soil will be defined in each single analysis. The dimension chosen for soil box are considering the dimension of the blade and the maximum distance and displacement the blade can reach.

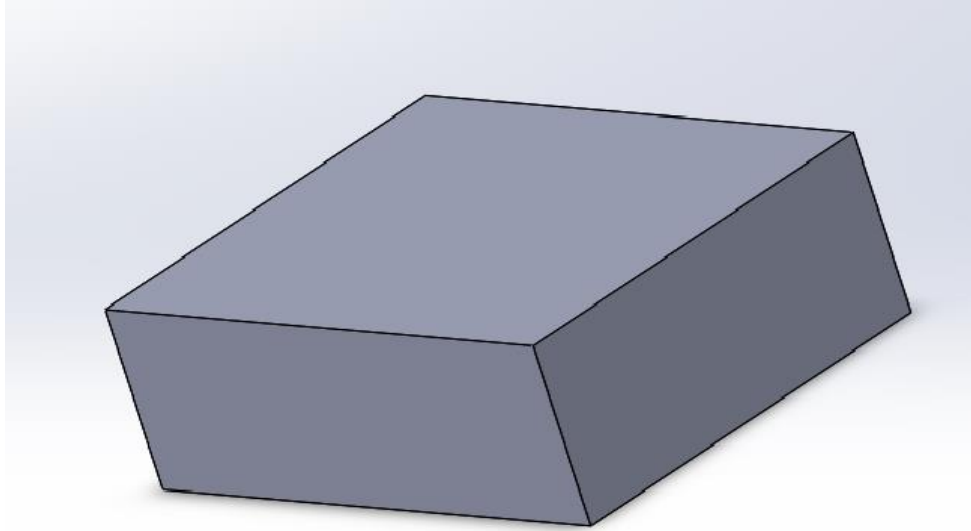


Figure 8 sand box

3.1.3 Rotating wheel with two identical blades.

Two identical blades will be attached to a rotating wheel of diameter 0.25m the blades will be chosen after the first analysis takes place considering the best blade geometry indicated in the results of the analysis.



Figure 9 wheel

3.2 Finite element mesh.

Meshing is a vital piece of the PC supported building re-enactment process. The mesh impacts the exactness, union and speed of the arrangement. Besides, the time it takes to make and mesh a model is regularly a critical part of the time it takes to get results from a CAE arrangement. From simple, programmed meshing to an exceedingly created mesh, ANSYS gives a definitive arrangement. Once the best plan is discovered, meshing advancements from ANSYS give the adaptability to create meshes that range in unpredictability from unadulterated hex to profoundly nitty gritty cross breed; a client can put the correct mesh in the opportune place and guarantee that a recreation will precisely approve the physical model.

There are 4 different physical preferences models for Ansys workbench.

-Mechanical.

-Electromagnetics.

-CFD.

-Explicit.

While the meshing methods for 3D bodies are:

-Automatic method: in which the bode will sweep if its possible, otherwise tetrahedrons are created.

-Tetrahedrons: or hybrid meshing in which all tetrahedral work is made. An algorithm setting is shown enabling you to pick how the tetrahedral work is made in view of your decision of one of the accompanying alternatives.

-Hex dominant: where a free hex dominant mesh is created. This option is recommended for bodies that cannot be swept. The work contains a mix of tet and pyramid cells with larger part of cell being of hex sort. Hex predominant cross section lessened component check.

-Sweep: a sweep mesh is constrained on "sweep able" bodies (counting hub sweep able bodies, which are not shown when you utilize the show sweep able bodies include). The Mesher will come up short if a cleared mesh can't be created on a body with a sweep strategy constrain.

-Multizone: in view of blocking approach utilized in ANSYS ICEM CFD Hexa. It consequently creates an unadulterated hexahedral mesh where conceivable and after

that fills the harder to catch areas with unstructured mesh. The Multizone mesh strategy and the Sweep mesh technique work likewise; nonetheless, Multizone has abilities that make it more reasonable for a class of issues for which the Sweep strategy would not work without broad geometry decay.

In this study two 3D bodies or geometries are used in simulation, a mesh strategy is selected separately for each of it according to its complexity of geometry and type of material. The physical preference selected for mesh is the **explicit** one since we are doing an explicit dynamics simulation. [2]

The first body is the structural steel blade, the automatic mesh method is been applied to it because of its complex geometry in which the elements and nodes are diffused according to each part of geometry such as edges, surfaces, fillets, etc.... the setting option that can be manually regulated is the element size, in which decreasing element size will give more results accuracy, until it reaches the minimum size. After many iterations on the available pc compatibility a 0.01m element size for the blade mesh has been selected to get a good result. Giving 1115 nodes and 3915 elements.

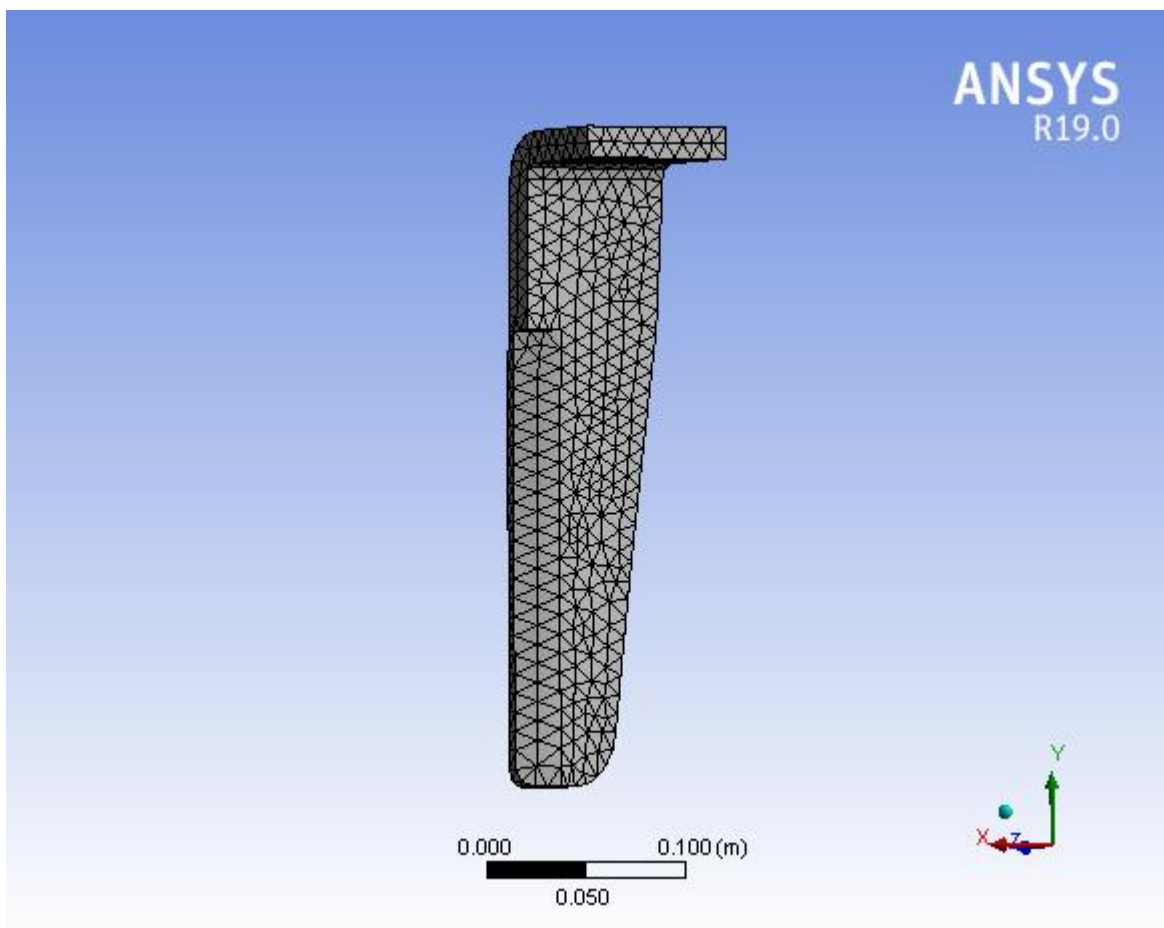


Figure 10 blade mesh

The second part is the soil box, for this body the Hex dominant mesh method is used since its geometry is simple and a large amount of interior volume is exerted. The element size selected after iteration is 0.02m giving a total of 23551 nodes and 21096 elements.

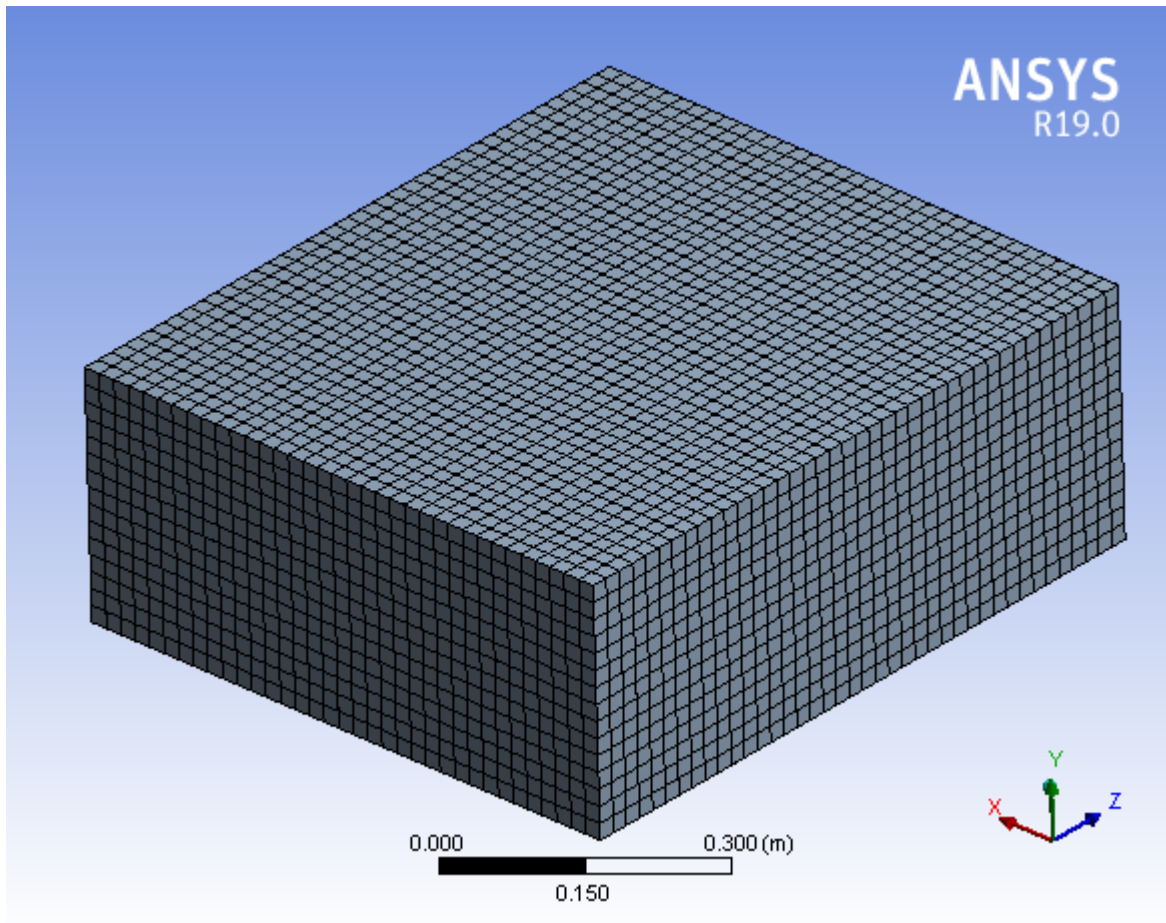


Figure 11 soil mesh

The mesh method used for the whole wheel is the automatic method, the number of nodes and elements are to be defined after defining the type of blade attached to the wheel.

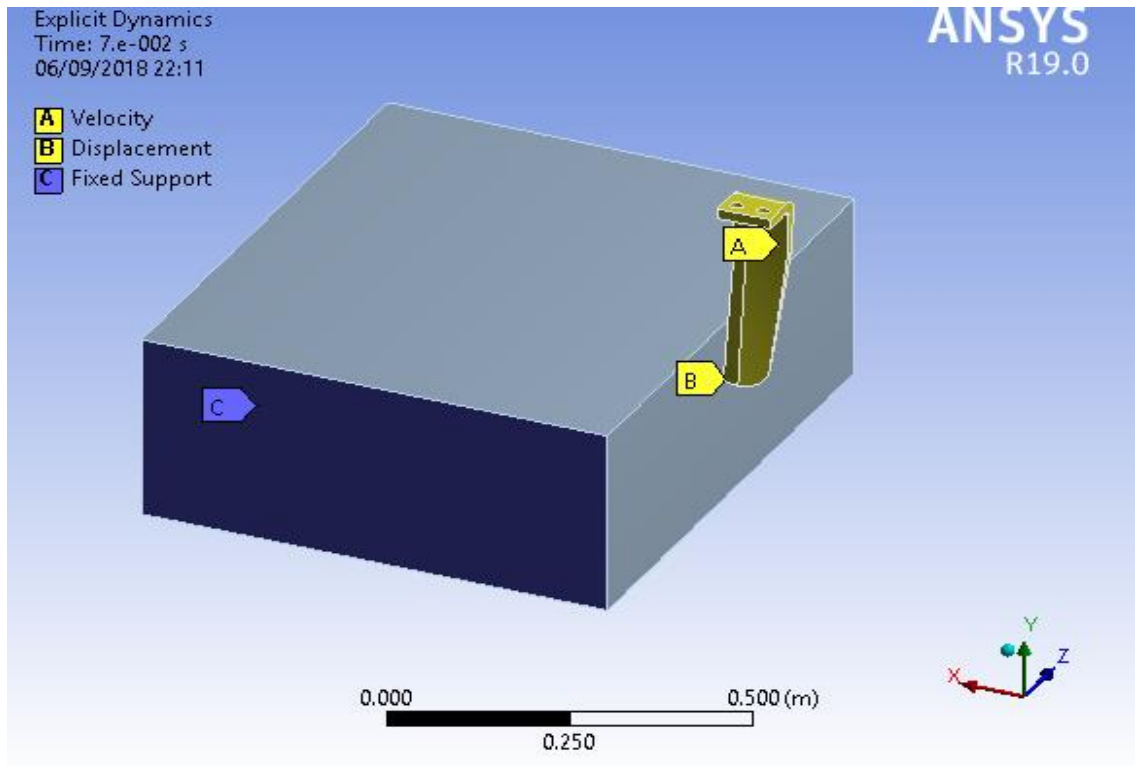
3.3 boundary conditions.

In this research two types of analysis are been carried, the first one is the linear moving single blade inside the soil in order to analyze the stress exerted by the soil on the blade and the deformation of soil generated by the blade and compare results of each type of blade. The second analysis is to find the reaction force done by each type of soil on the rotating wheel consists of two identical blades in which the blade type will be chosen according to the results of the first analysis.

Going back to the first analysis the blade moving in the soil is affected by many conditions in which the blade is connected to the wheel with a certain rotating speed, and the wheel is connected to a tractor that moves in a certain speed, additionally there is a friction between the soil and the blade that should be indicated according to every type of soil.

The linear speed of the blade is calculated by the addition of the speed of the tractor to the tangential speed created by the rotation of the wheel. The tractor speed is 5km/h which is about 1.4 m/s while the rotating speed of the wheel is 350rpm which is about 36.5 rad/s multiplying it by the radius of the wheel which is 0.125m we got the tangential velocity of about 4.6m/s in total the linear velocity of the blade is 6m/s that is applied in one direction and putting zero displacement as a boundary conditions for the blade in the other two directions.

As a boundary conditions applied to the soil box a fixed support was applied to the 4 faces of the box keeping free the upper face and the face where the interaction occurs between the blade and the soil in order to get conditions similar to the real ones.



The friction coefficient value in the interaction between the blade and each type of soil is determined according to the “NAVFAC standards” in which values were defined according to experimental data for a steel sheet piles against several types of soil, the values chosen for the types of soil used in this analysis are mentioned in the following table. [8]

Soil	Friction coefficient
Dry sand	0.3
Sandy clay	0.25
Sandy gravel	0.4
Silty sand	0.2

In the second analysis the same soil box is used and the same boundary conditions were applied to it, however for the wheel with two blades attached to a remote displacement setting was applied with 36.6rad and for every 1s which gives 350rpm rotating around the coordinate axis directed toward up and moving with the velocity of tractor forward toward the soil and all other possible linear or rotating displacements have been defined 0. The time of the analysis selected is 0.14s in which the center of the wheel will pass 0.224m in the unique direction and rotates 5.124 radians.

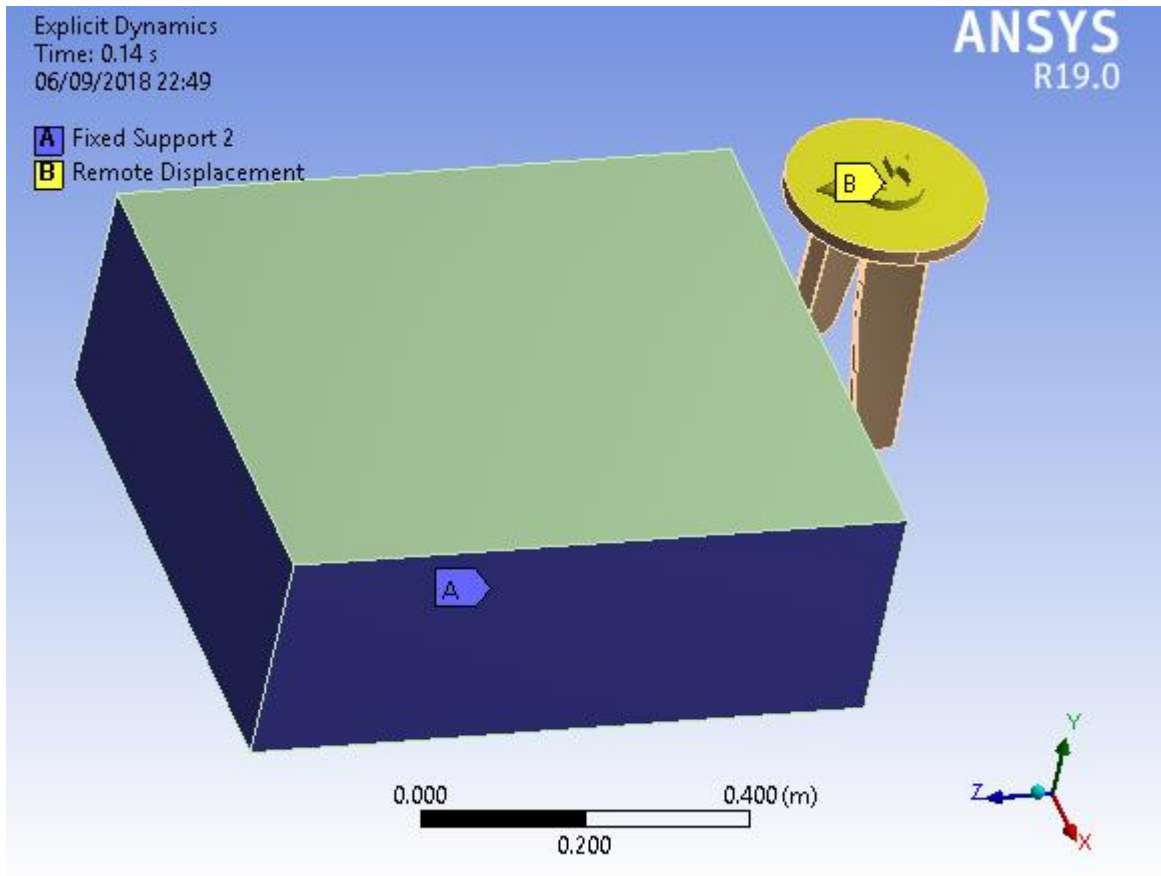


Figure 12 boundary condition applied

Chapter 4

4 Results of the analysis.

4.1 Results of the first analysis.

The first analysis was done considering the single blade is moving with constant velocity of 6m/s in only one direction leading to an interaction with the soil with depth of 10cm. In explicit dynamics analysis many results are available for the simulation the results must be defined before giving order to the solver to start. The results defined to be found for the first analysis is the equivalent (von mises) stress on the blade, and the deformation of the soil. After finishing the solver analysis results are shown step by step by an animation video and data of solution is given by a table in a function of time. The figure below shows how the interaction is presented by Ansys explicit solver in a defined time.

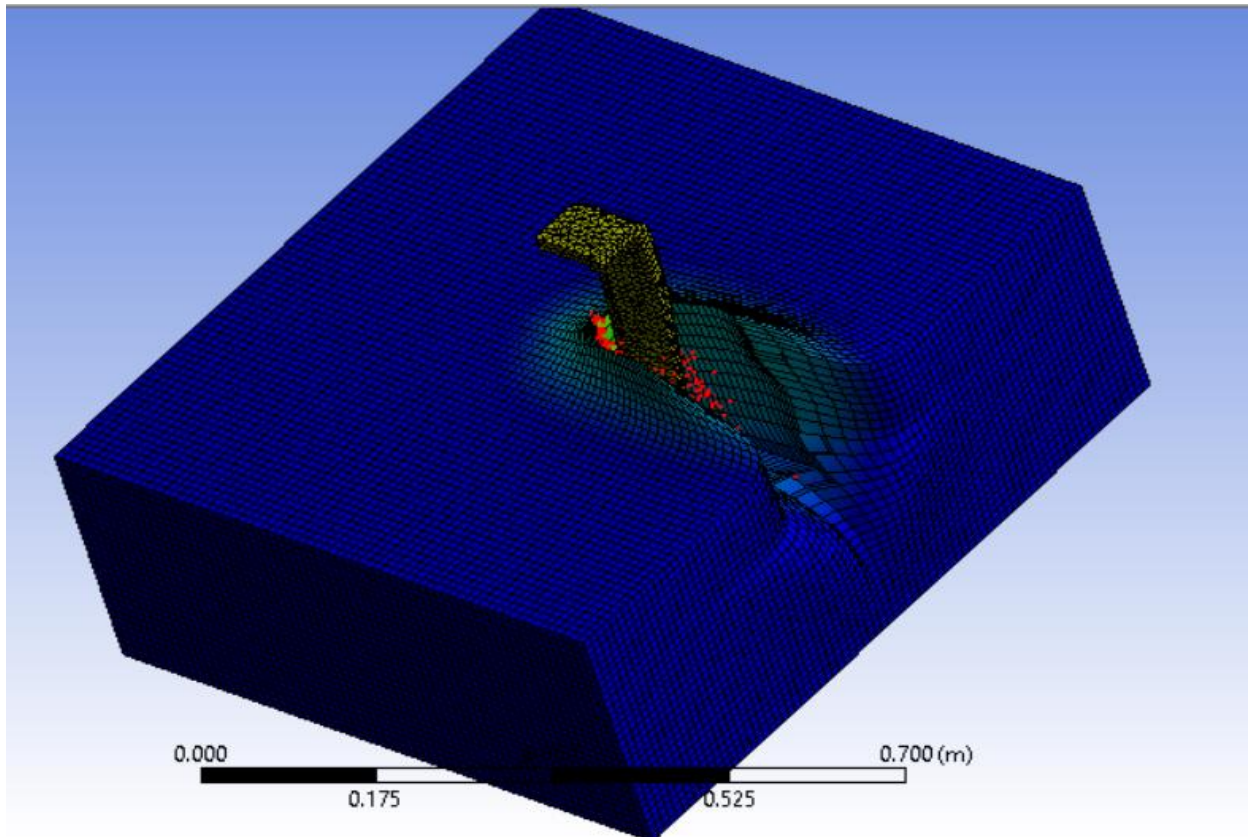
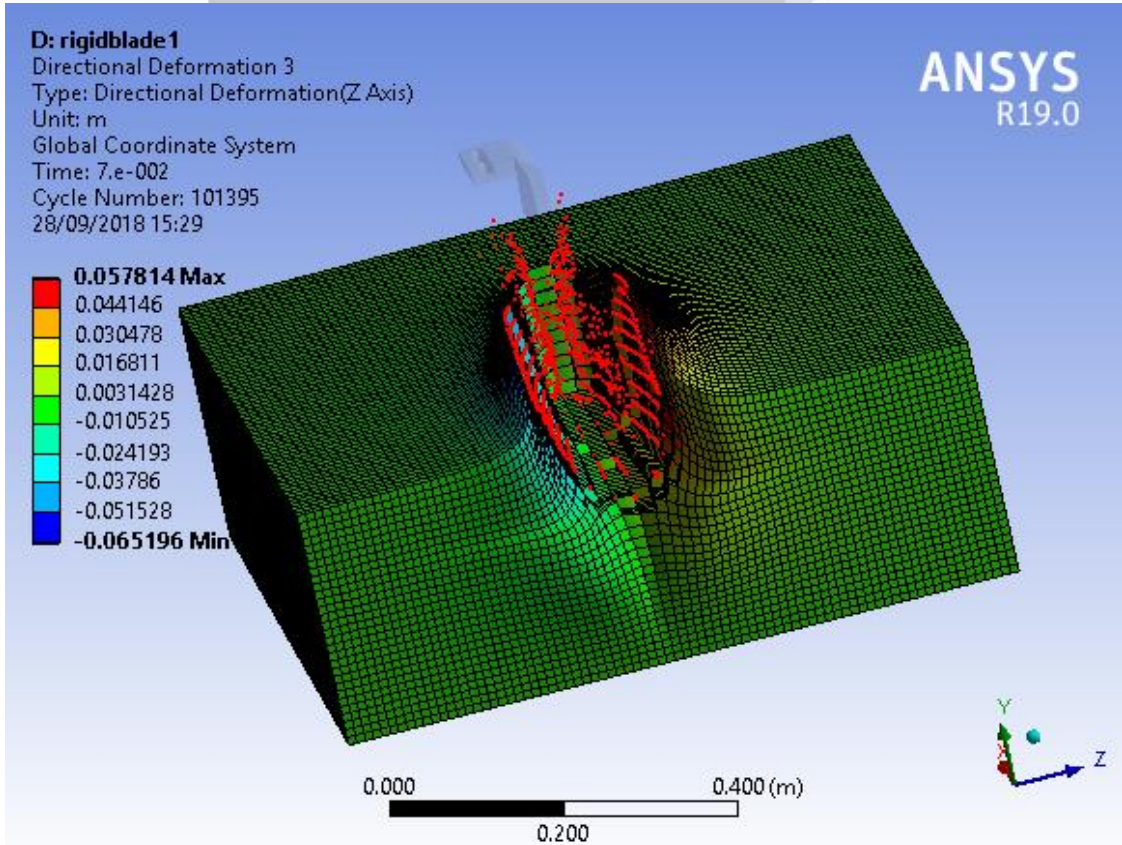
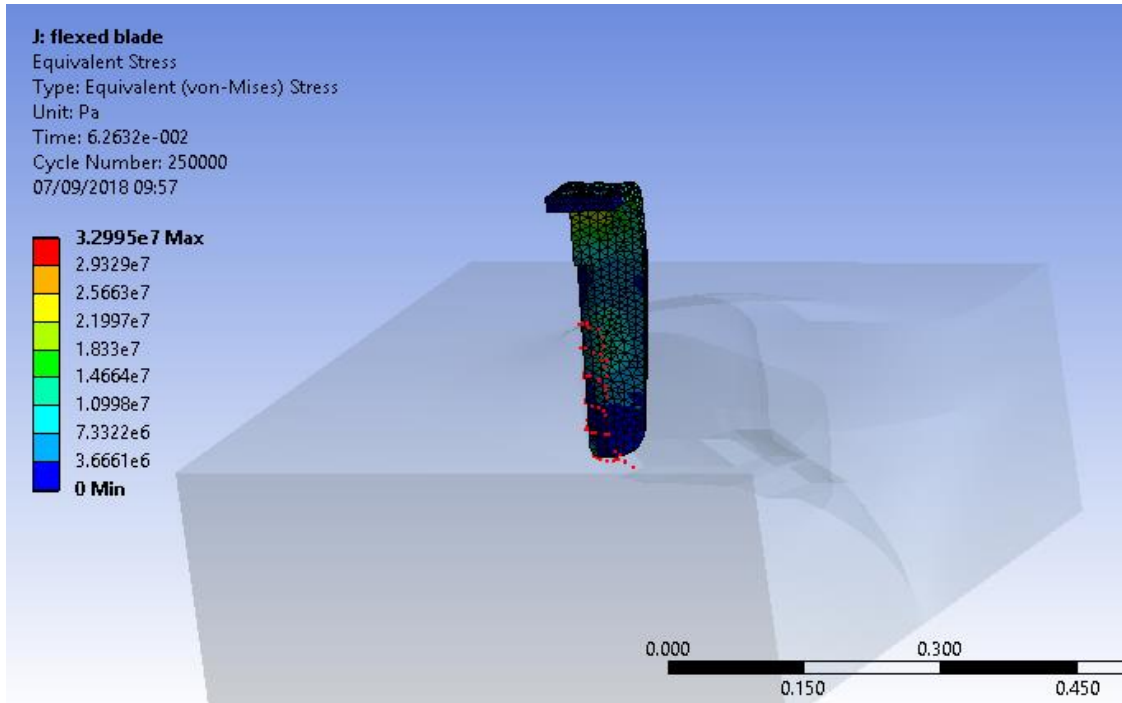
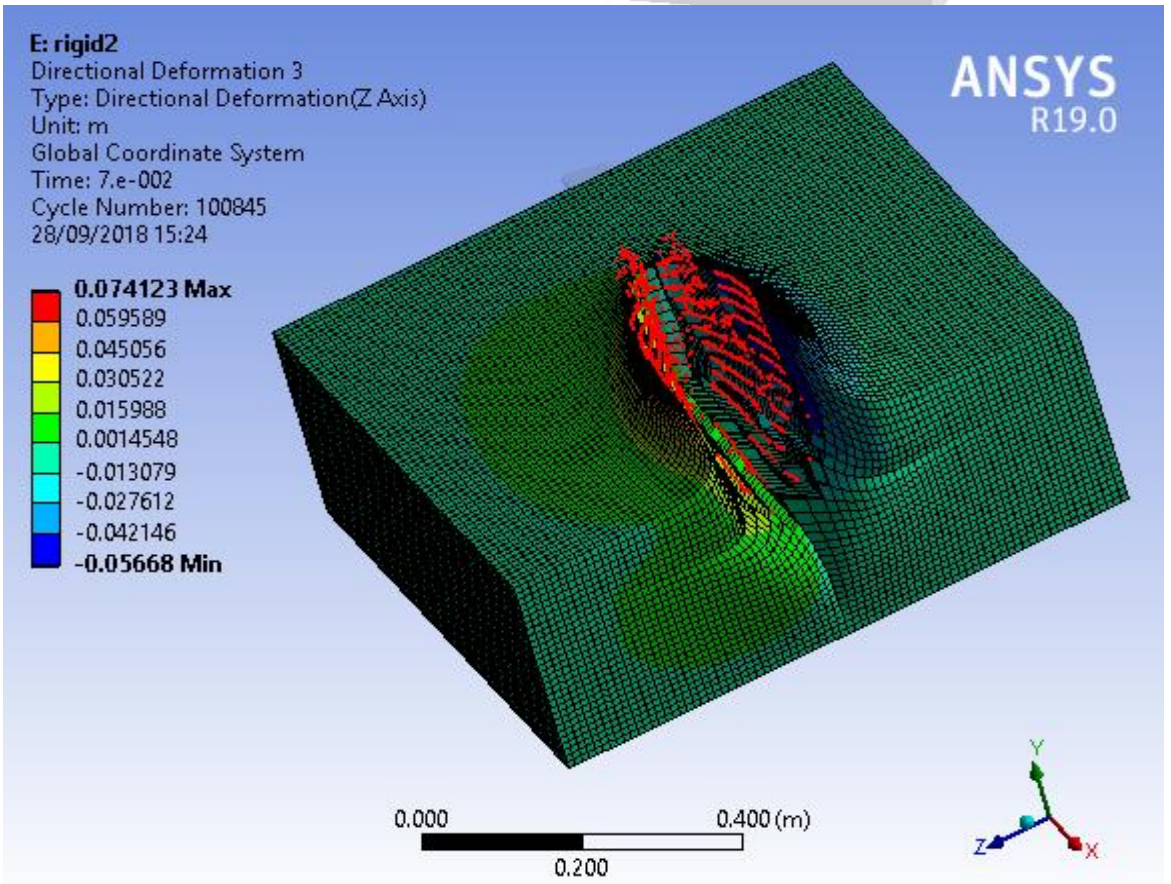
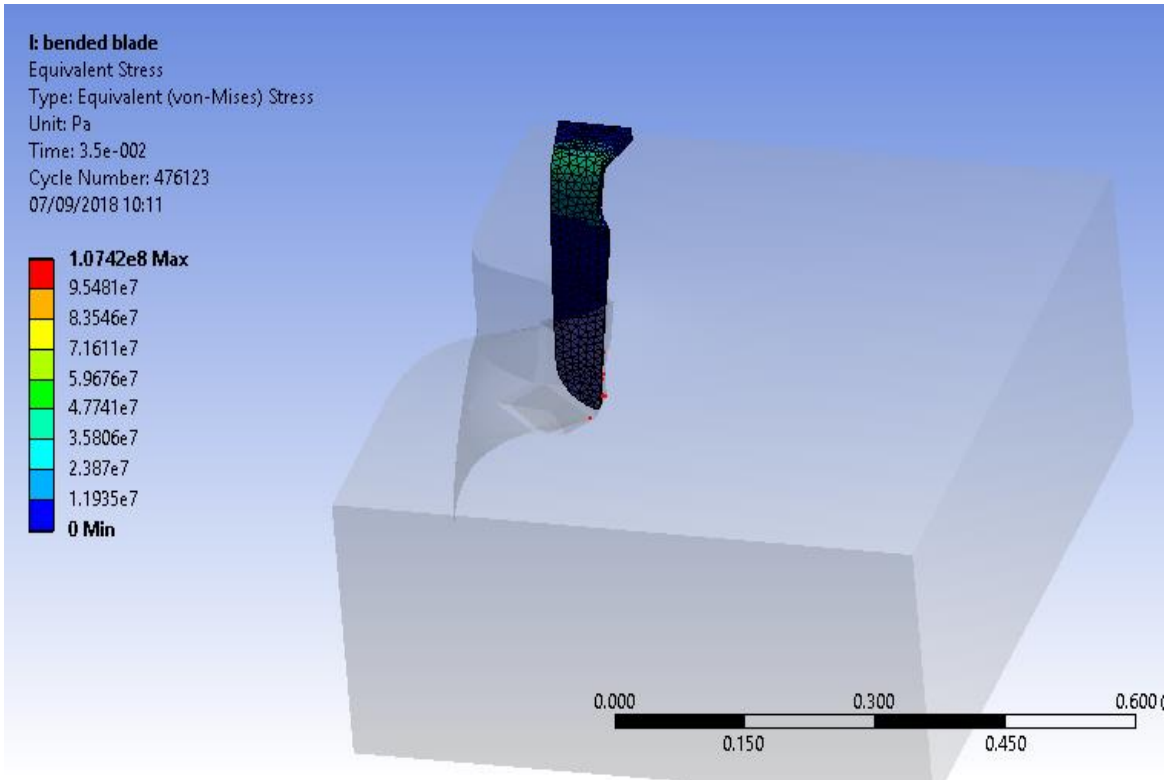
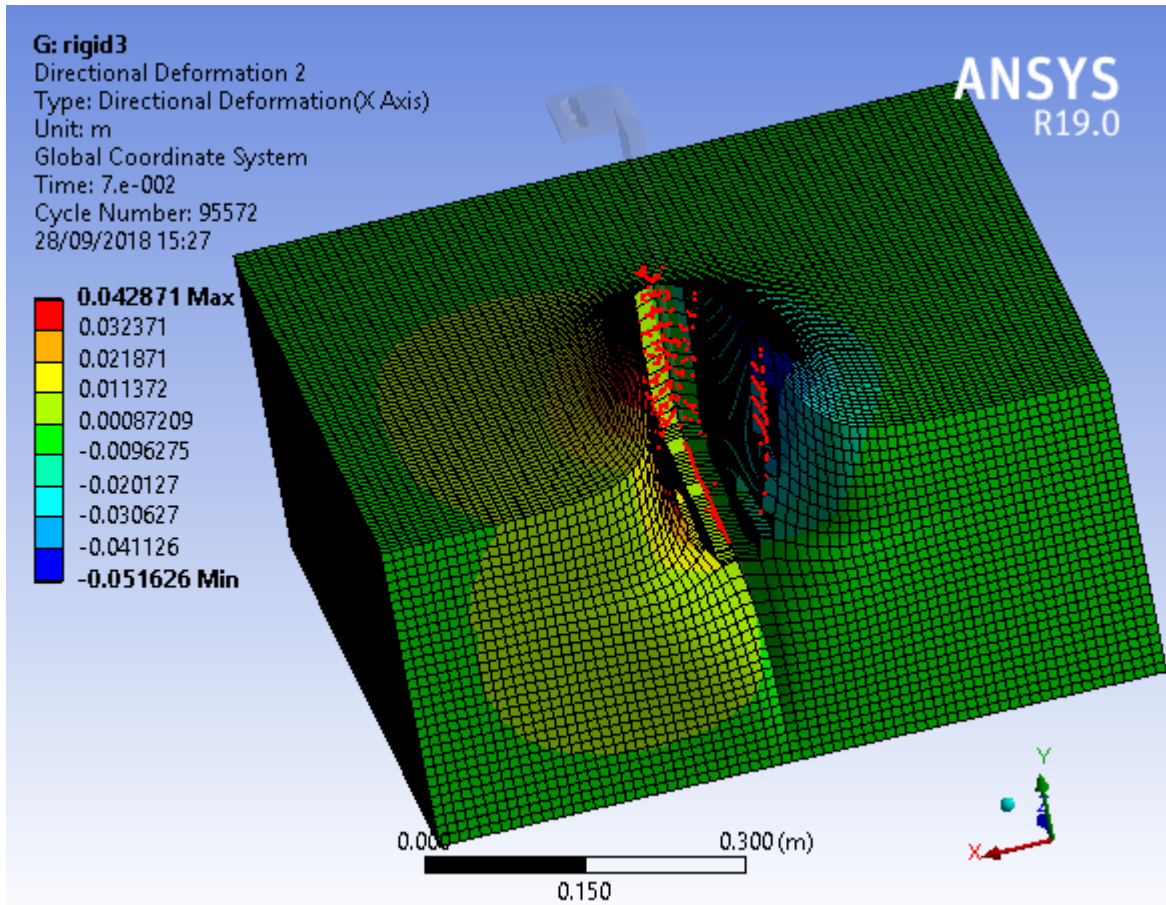
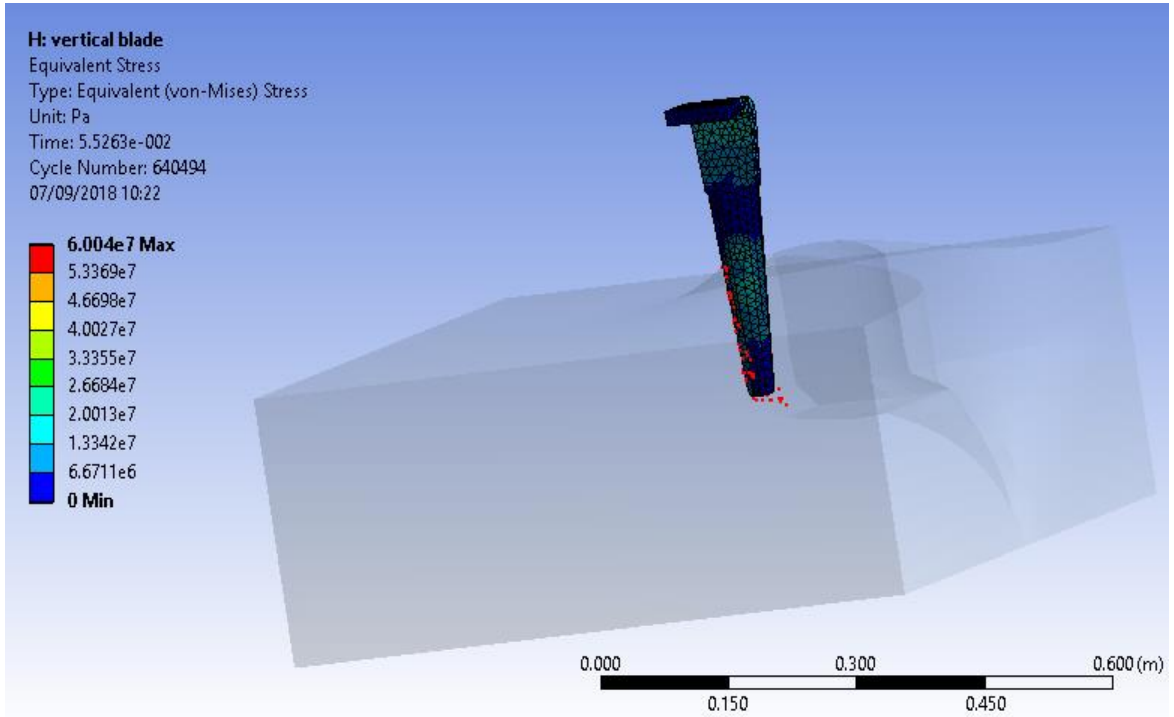


Figure 13 results appearance

The results to be calculated have been chosen the same for the three types of blades, working on the same type of soil which is the sandy clay, that is the most type of soil usable in farms and agricultural lands. The results of the three blades are shown in the figures below.







In the table below the results shown above are summarized.

blade	Maximum equivalent stress (pa)	Maximum deformation of soil in horizontal direction (m)	Max deformation in upward direction (m)
Flexed blade	3.2995e+007	0.058	0.14
Bended blade	1.07e+008	0.07	0.13
Vertical blade	6e+007	0.04	0.06

4.2 Results for the second analysis.

The blade chosen to be assembled to the disk was the flexed blade since it gave the best results regarding deformation of the soil and low stress reacted on the blade. The analysis was applied on the 4 types of soil to obtain the force reaction applied from each type on the blades. The analysis has been done 4 times applying the same boundary conditions every time changing only the type of soil material attached to the soil box in every time. After choosing the type of blade to be attached to the disk from the results of the first analysis its time to define the mesh type, number of nodes, and the number of elements of the whole blade. The mesh type applied to the wheel is the automatic one since the geometry of the wheel is so complicated. The number of nodes reached was 25902, and 123578 elements, those numbers were obtained defining the element size 0.005m after iteration process done to reach the most accurate solution decreasing the element size.

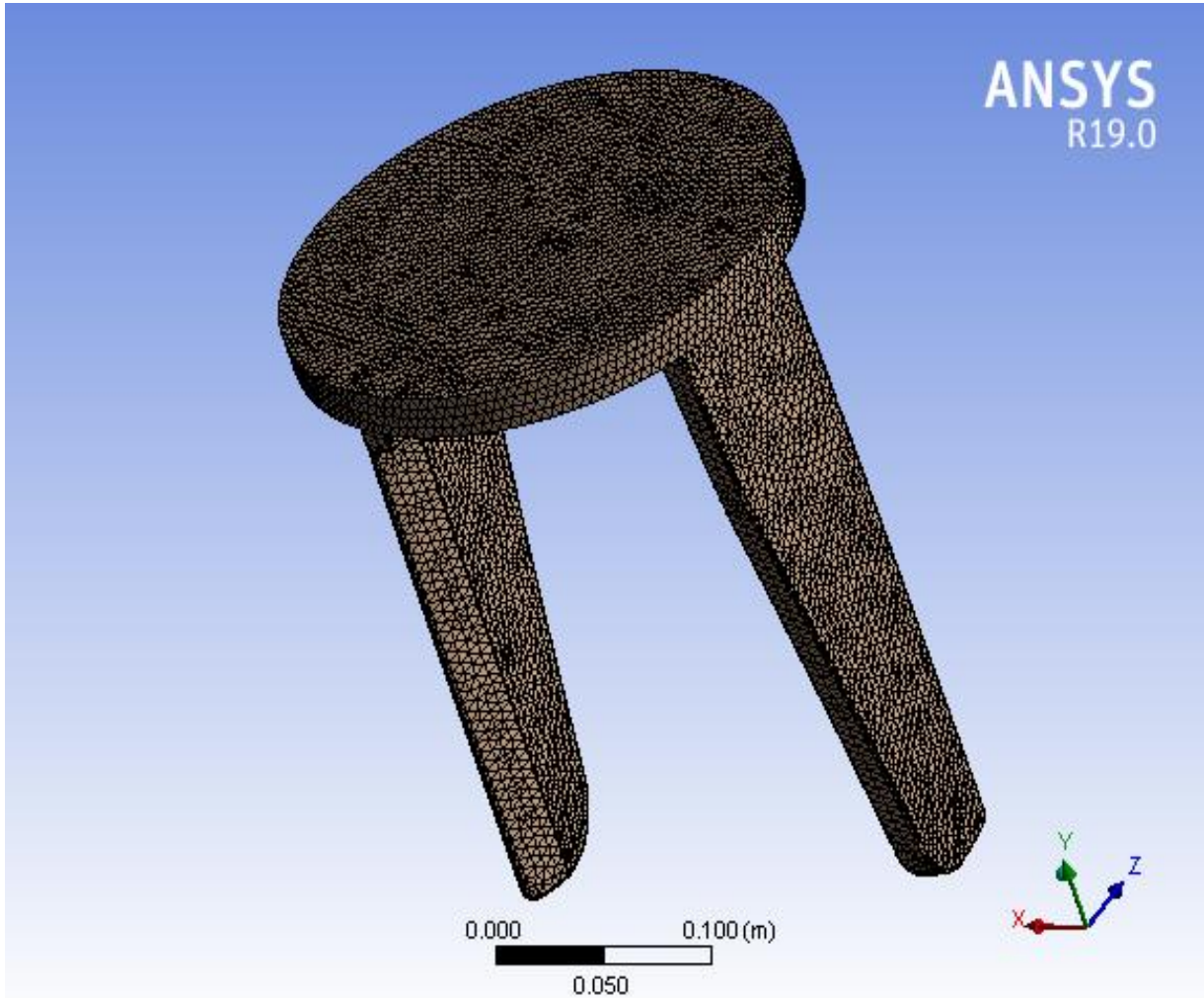


Figure 14 mesh of the wheel

The results gotten from this analysis were regarding the reaction force acting on the blades of the wheel during its rotation over time, the results are shown in a graph that shows the variation of force with respect to time, those results were modified later using MATLAB code to be clearer and easily ridden. The reaction force parameters were divided into two important sets, the first one is the maximum force reaction at the first point of the interaction for each type of soil shown in the table below.

Type of soil	First (maximum) interaction force(N)
Dry sand	8.1608e+007
Sandy clay	2.5779e+008
Sandy gravel	2.6467e+008
Silty sand	6.2249e+007

The second part of the solution was the force reaction during the rotation and the peak reached in every turn of the wheel, those results are shown in 4 different graphs each one for a different soil type.

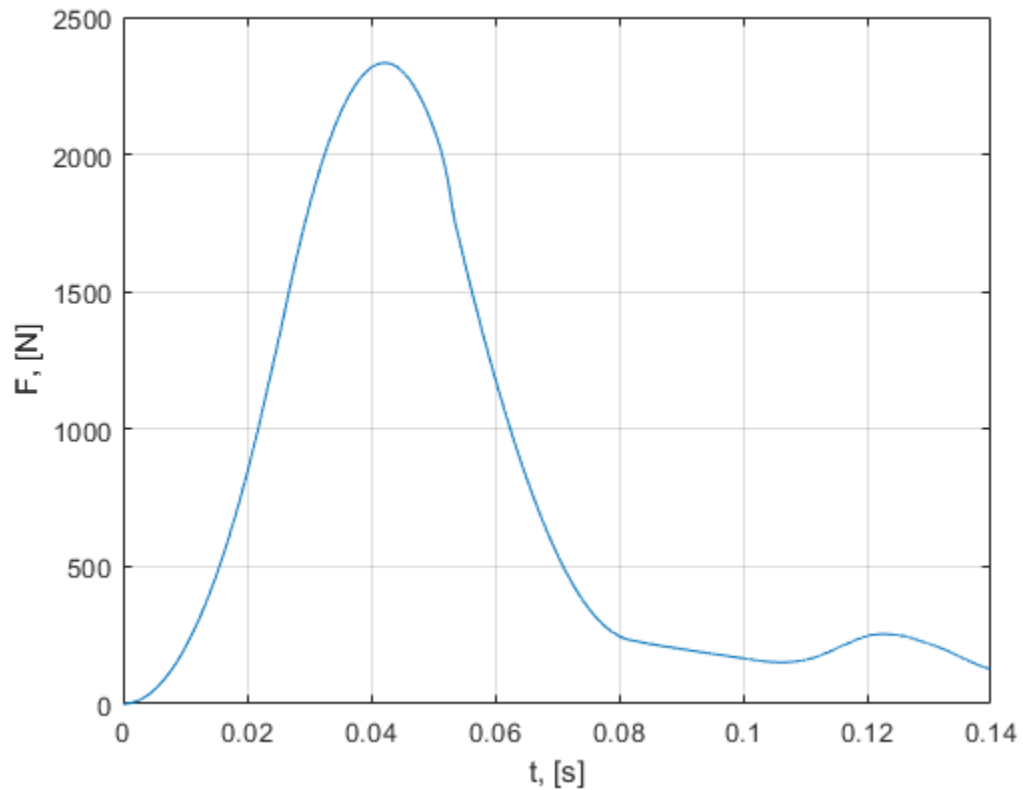


Figure 15 reaction force of dry sand on the wheel blades

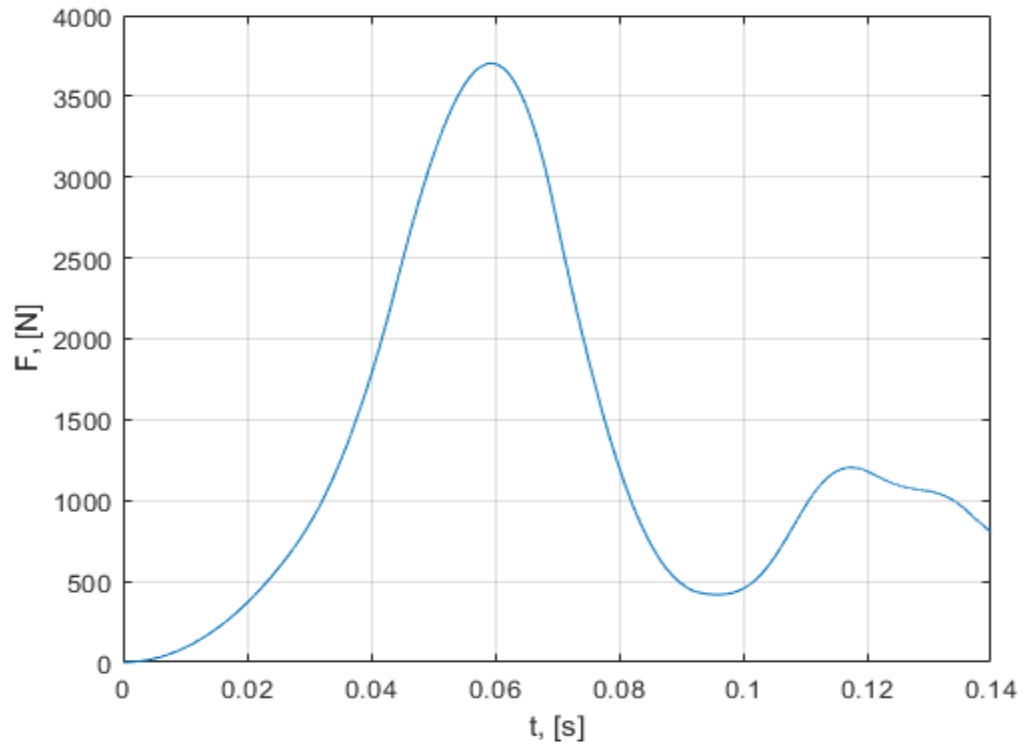


Figure 16 reaction force of sandy clay on the wheel blades

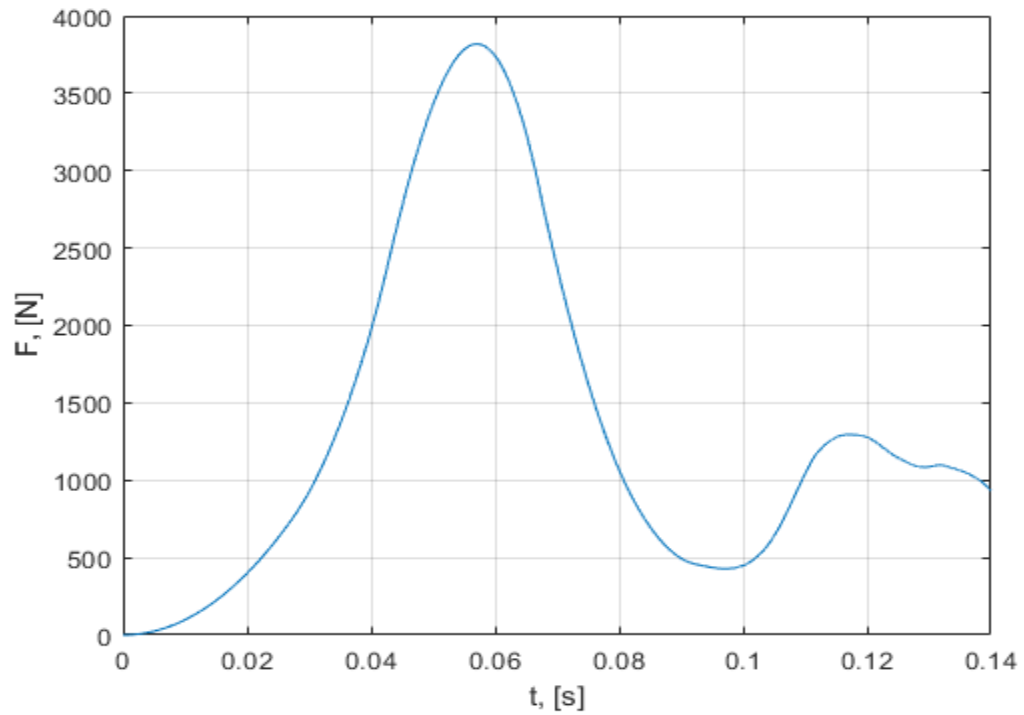


Figure 17 reaction force of sandy gravel on the wheel blades

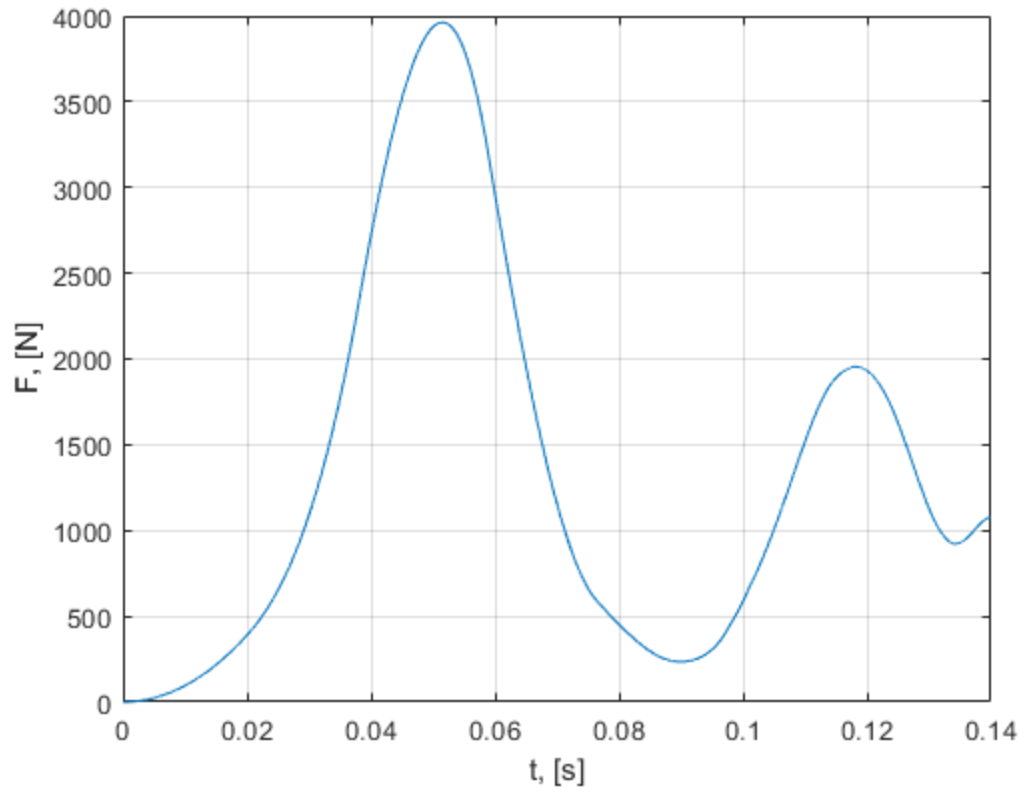


Figure 18 reaction force of silty sand on the wheel blades

5 Conclusion

This project used FINITE ELEMENT ANALYSIS (FEA) for two main purposes, the first purpose is to study the effect of the geometry of the blade of a harrow on the soil deformation and on its strength or life time by calculating the stress exerted on it. In this study, a good results were gotten for the flexed blade that showed a good soil deformation with an acceptable or low stress exerted on the extremities of the blade, but it can not been said that it's the best between the blades since in agriculture the need of deformation of the soil depends on the type of plants and the type of soil exerted in the field.

The second purpose was finding the force exerted on the blade of a complete harrow wheel in which the results will be useful for optimizing of the blade life knowing the soil type of the field, and for later studies in which the power and energy needed by the tractor could be calculated based on the force values found in which indicates the maximum speed of the tractor and the fuel consumption in addition to other important parameters.

In summary the study is useful for both farmers and companies, in which it allows the farmers to choose the suitable blade depending on their fields, and for companies in order to optimize the blade life and improve its work for more soil-tool interaction cutting efficiency.

5.1 Recommendations for future work.

1. Only one penetration depth was studied in this research. Parametric study should be conducted with different blade cutting depths.
2. Other useful parameters could be found using FEA, such as energy and power can be calculated in later research.

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