

# **Design and Optimisation of Blades for Rotavators**

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**ABSTRACT:** Rotary tiller or ROTAVATOR (derived from rotary cultivator) is a tillage machine designed for preparing land by breaking the soil with the help of rotating blades. Stubbles & residues of previous crop are chopped into pieces and thoroughly mixed in soil to form organic manure. Rotavator plays a vital role in helping the farmer to plough their land in a much faster and effective way. The aim of this project is to design and optimize the Rotavator Blade for better life and performance on field. Hence any improvement in the field performance of the same would in turn, augment the productivity in the agricultural sector. Design and modelling of the Rotavator's Rotor assembly has been completed. The dynamic analysis of rotavator blades during the tilling operation on soil is obtained using the FEA tool Abaqus.

**KEYWORDS:** Rotavator, Tilling, Finite element Analysis in Abaqus, Soil Modelling.

## **I. INTRODUCTION**

India ranks second worldwide in agricultural farm output. India has shown a steady average nationwide annual increase in the kilograms produced per hectare for various crops, over the last 60 years. One of the main contributing factor for the steady growth is the onset of mechanization of the farm equipments leading to a steady increase in the yield output of the farmers Tillage is the most important operation in agriculture. It is done mainly to loosen the upper layer of soil to mix the soil with fertilizer and to remove weeds.

Rotary tiller or ROTAVATOR (derived from rotary cultivator) is a tillage machine designed for preparing land by breaking the soil with the help of rotating blades suitable for sowing seeds (without overturning of the soil). It also plays a vital role in eradicating weeds, mixing manure or fertilizer into soil, to break up and renovate pastures for crushing clods etc. It offers an advantage of rapid seedbed preparation and reduced draft compared to conventional tillage. The first rotavator was introduced in US by a Swiss manufacturer in 1930s.

Rotavator action involves the direct application of tractor engine power through a rotor and blades of a special design to soil preparation in establishing the ideal growth conditions for seedlings and seeds. In this project, the work is done towards investigating soil dynamic behaviour resulting from the impact of a rotary blade against a soil surface. It is difficult to express the actual shape of the blade mathematically because it consists of three-dimensional curved lines. This needs to be approached by the help of FEA tools in order to predict the real-time scenario.

## **II. DESIGN METHODOLOGY**

### **A. Aim of Design**

- To design the tillage tool aiming at reduction in weight, cost and also at improving its field performance, so as to obtain higher weed removal efficiency.
- Try to reduce the common causes of failure – unwanted bending and excessive wear.
- Prime results in force analysis- maximum peripheral force on blade surface and torque.

**B. Important Aspects in Design**

- 4-6 discs or flanges are mounted on a rotating hollow shaft which is driven by a drive (in this case, a GEAR DRIVE), on each of which L-shaped blades are mounted.
- These L-shaped Blades generates impact on the soil surface and throws or uproots the soil upward thus pulverizing the soil and breaking it into clods.
- The gap between blades and shield is adjustable which controls the degree of pulverization. Lowering this gap increase pulverization.
- The cover helps to distribute the soil equally on ground surface to get levelled land.
- The rotor usually rotates in the same direction as the tractor wheels. Each blades cuts a segment of soil as it moves downward and toward the rear.
- Most rotary tillers make either 2 or 3 cuts per revolution. Because of the high peak torques developed during each cut, it is important to STAGGER the blades in the different courses, with equal angular displacement between them, so no two blades strike the soil at the same time. In the design at hand, the stagger angle is observed to be 10 degrees.

**C. Modelling**

Based on the sketches of the rotavator system under consideration, 3-D sketches were completed. Modelling of the existing 45-hp rotavator rotor assembly and part drawings in 3-D was completed using CREO PARAMETRIC 2.0.

The essential components of the Rotor assembly (the rotating parts) are as follows:

- BLADES – Right Hand and Left Hand type blades (18 each in numbers) – 36.
- HOLLOW SHAFT.
- FLANGES – End Flanges (2 numbers) and Middle Flanges (5 in numbers) – 7 and
- M12 NYLOC nuts – 72.

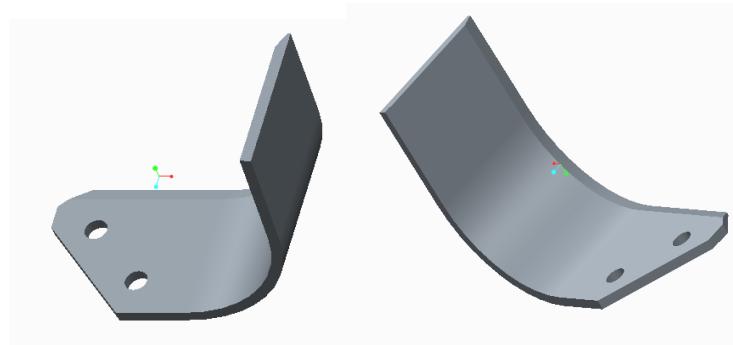


Figure 1: Left Hand and Right Hand Blades respectively

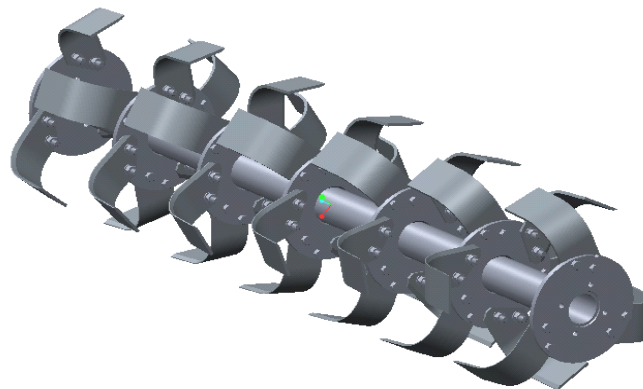


Figure 2: Completed assembly drawing of the rotavator rotor system.

### III. KINEMATICS OF ROTAVATOR BLADES

Design principles and equation of rotary blades and rotary shafts has been formulated considering their relative motions and actual operations between soil and these components. The equations of motion have been applied to study rotary blade. The trajectory of motion of the rotary blade has to be determined in order to select the rotor radius of the rotary blade, the number of blades on a disc z, and the angular and translational velocities  $\omega$  and  $V_f$  respectively of the drum.

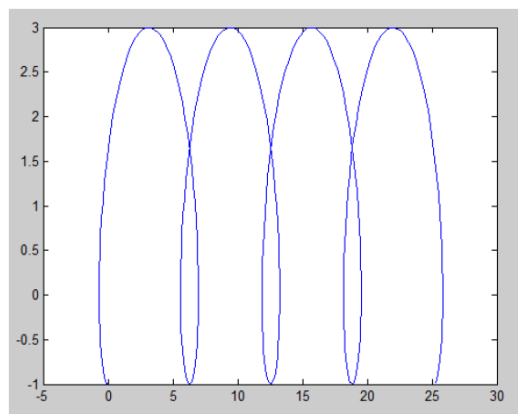
#### A. Motion Characteristics

Rotovators execute combined rotational and forward motion during tillage operations. The path of the motion of each point on the rotavator depends on the circumferential and forward travel velocities as well as the direction of rotation. An understanding of the rotavator kinematics is essential for the analysis of its operations.

Any point on the rotor travels a path which is a combination of the machine forward motion and the distance from the rotational axis to the point of interest.

$$\left. \begin{aligned} x &= V_f t \pm R \cos \alpha \\ y &= R(1 - \sin \alpha) \end{aligned} \right\}$$

One may thus consider that the path of a tine is similar to that of a circle rolling without any slip on the X-axis. Geometrically, this trajectory is a trochoid or a curate cycloid. Using the equation mentioned above, the path of a point on the blade tip could be traced using MATLAB 2-D plot as shown in the figure



MATLAB CODE:

```
>>t=0:1.8*pi;
>> plot(1*t-2*sin(t), 1-2*cos(t))
```

Figure 3: Path of the Cutting Profile traced by a point on the Blade Tip.

#### B. Blade Characteristics

1. **Stagger Angle:** At any point of rime only one blade must be in contact with the soil phase in order to impart proper cutting motion as well as to avoid shock during forward travel. Hence an angle is provided between 2 similarly positioned blades in different flanges.

Number of blades = 36

Total angle to be covered during the entire rotation =  $360^\circ$

Hence Stagger angle =  $360/36 = 10^\circ$

**2. Bite Length:** Bite length or blade delivery is determined by considering the process of soil cutting by two adjacent blades in one vertical plane and mounted on the same side of the flange. It can simply be defined as the horizontal distance between points of contacts of adjacent blades mounted on the same side of the flange.

$$L_b = V_f \times t_b$$

But we have,  $t_b = 2\pi z\omega$

On substituting for our problem we get,  $L_b = 57.69$  mm.

BITE LENGTH  $L_b$  is one of the most important technical parameters of a rotavator. It determines the degree of chopping of the processed soil.

### C. Static Analysis

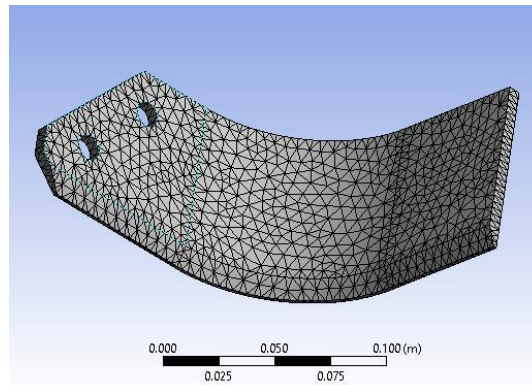


Figure 4: Finite element meshing of the LH blade.

Static Analysis of Rotavator Blades was completed using the FEA tool ANSYS WORKBENCH. Only a Single Blade (LH Blade) is taken for the purpose of Static Analysis.

**Boundary Condition:** flange end of the Blade is fixed.

**Pressure:** Load of 14.172 KPa applied on the load carrying faces.

**Meshing:** Fine- tetrahedral.

In the existing Blade Design: Blade Angle =  $95^\circ$

Now, the Blade angle is varied as  $85^\circ$ ,  $90^\circ$ ,  $95^\circ$ ,  $100^\circ$  and  $105^\circ$  and the static analysis is carried out for each and the results obtained were plotted as shown in the table below.

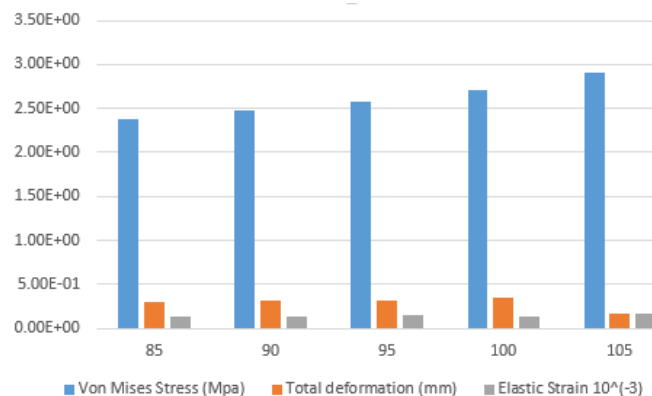


Figure 5: Chart showing the variation of Von Mises Stress, Total deformation and Elastic Strain with varying Blade Angles.

It is found that the increase in the blade angle would result in increase in Von-mises Stress, Deformation and the Strain values.

### III. SOIL PROPERTIES AND SUITABLE FAILURE MODEL

#### A. Shear Strength

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subject to shear strains. The shear strength of soil depends on the effective stress, the drainage conditions, the density of the particles, the rate of strain, and the direction of the strain. The average normal inter-granular contact force per unit area is called the effective stress.

If water is not allowed to flow in or out of the soil, the stress path is called an undrained stress path. During undrained shear, if the particles are surrounded by a nearly incompressible fluid such as water, then the density of the particles cannot change without drainage, but the water pressure and effective stress will change. For undrained, constant volume shearing, the Tresca theory may be used to predict the shear strength, but for drained conditions, the Mohr–Coulomb theory may be used.

#### B. Mohr Coulomb Theory of Soil Failure

When a soil sample has failed, the shear stress on the failure plane defines the shear strength of the soil. It can be assumed that a failure plane exists and it is possible to apply principal stresses and measure them in the laboratory by conducting a tri-axial test. Then, the Mohr circle of stress at failure for the sample can be drawn using the known values of the principal stresses. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion ( $c$ ) and the angle of internal friction, commonly known as friction angle. The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the y-axis and the confining stress on the x-axis. The y-intercept of the curve which fits the test results is the cohesion, and the slope of the line or curve is the friction angle.

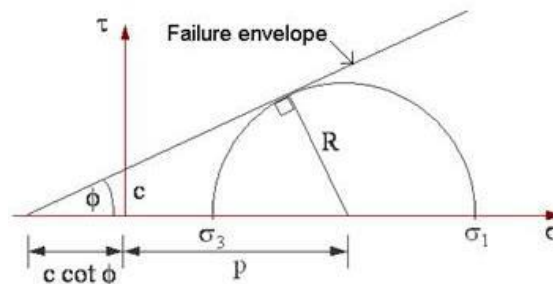


Figure 6: Failure Envelope and Shear plane of failure for soil.

If data from several tests, carried out on different samples up to failure is available, a series of Mohr circles can be plotted. It is convenient to show only the upper half of the Mohr circle. A line tangential to the Mohr circles can be drawn, and is called the Mohr-Coulomb failure envelope. The Mohr-Coulomb model is merely a linear simplification of a portion of the entire envelope over a limited range of normal stresses. If testing were performed over a large enough range of normal stresses the curvature would become more apparent. True shear strength envelopes are found to be most accurately described by hyperbolic functions.

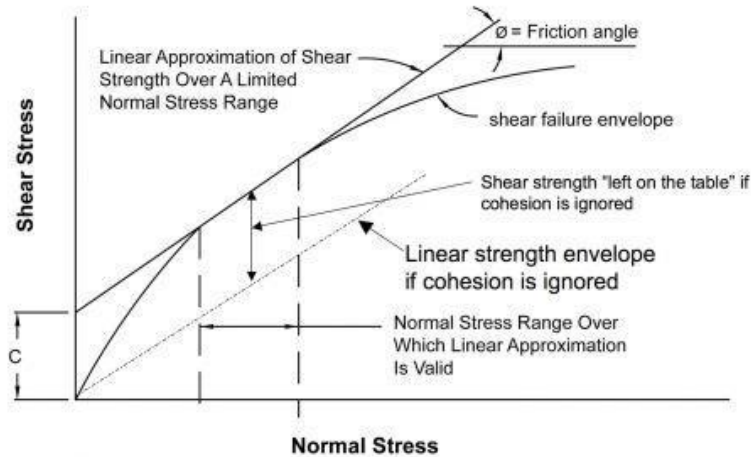


Figure 7: Actual Failure Model

### C. Cohesion and Soil friction angle

Cohesion is a term used in describing the shear strength soils. Its definition is mainly derived from the Mohr-Coulomb failure criterion and it is used to describe the non-frictional part of the shear resistance which is independent of the normal stress. In the stress plane of Shear stress-effective normal stress, the soil cohesion is the intercept on the shear axis of the Mohr-Coulomb shear resistance line.

Soil friction angle is a shear strength parameter of soils. Its definition is derived from the Mohr-Coulomb failure criterion and it is used to describe the friction shear resistance of soils together with the normal effective stress. In the stress plane of Shear stress-effective normal stress, the soil friction angle is the angle of inclination with respect to the horizontal axis of the Mohr-Coulomb shear resistance line. Friction Angle is a measure of the ability of a unit of rock or soil to withstand a shear stress. It is the angle ( $\phi$ ), measured between the normal force (N) and resultant force (R), that is attained when failure just occurs in response to a shearing stress (S). Its tangent (S/N) is the coefficient of sliding friction. Its value is determined experimentally.

## IV. ABAQUS MODELLING OF THE SOIL-CUT DYNAMICS

### A. Modelling

An attempt was made at creating the dynamic motion simulation of rotavator over soil bed. Only a single flange of the rotor with 6 blades was modelled for the purpose of dynamic simulation. Blade was assumed as ANALYTIC RIGID. Soil properties were assumed based on MOHR COULUMB CRITERION. Dynamic Explicit analysis of the interaction of the rotary blades with the soil model was carried out.

Mesh Definition:

- EC3D8R: 8-node linear Eulerian brick element for the soil bin.
- C3D10M: A 10-node modified quadratic tetrahedron for the blade system.

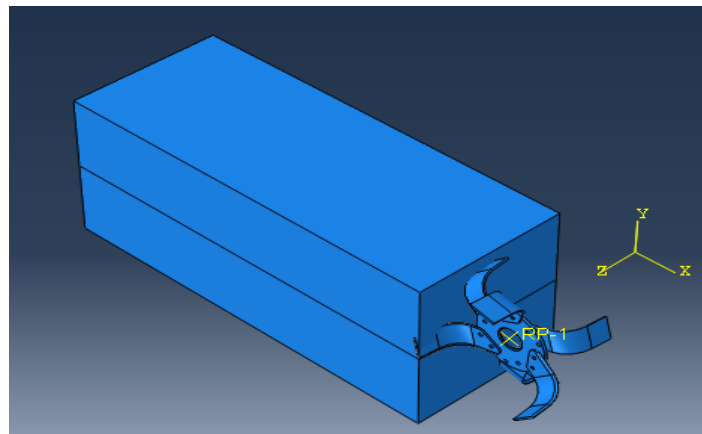


Figure 8: Abaqus Model for the Blade-cut analysis/

#### Load and BC:

- All d.o.f. were arrested for the soil bin.
- A reference point (RP1) was created and the whole rotor flange was tied to the point so that it moves as rigid body w: r: t the reference point.
- Rotary motion of 210 rpm (about Z – axis) and translatory motion of 1.5 m/s (in the direction of negative X – axis) were applied as velocity boundary condition to this reference point.

#### Interaction:

General surface-surface contact was established between the rotor body and the soil bin. To ensure contact among them the concept of Master-Slave surfaces was implemented. Generally for bodies of different densities, the interaction is defined as Master-Slave type. The body with higher resistance to deformation is almost always chosen as the Master and the one that tends to deform more is selected as the Slave. On contact, the master penetrates the slave surface, even without the application of contact forces.

#### B. Eulerian, Lagrangian and CEL approach:

An **Eulerian** frame is fixed in space. The considered domain is divided into elements. With deformation and movement, materials flow through the elements. Advantages of the Eulerian approach are that the mesh does not change per time step and that large deformations of the rod do not increase the needed computation power. For this reason, the Eulerian frame is used widely in fluid dynamics.

A **Lagrangian** frame moves with the material. According to the Lagrangian approach the movement of mesh nodes is connected to the material movement. In this way the interface of the material is tracked precisely. Large deformations however, lead to mesh tangling implying a less precise solution. Re-meshing is needed in this case, costing computational power. When considering materials with high elastic or Young's modulus, deformations are relatively smaller and the Lagrangian frame is attractive. For this reason, the Lagrangian frame is used widely in structure mechanics.

The **coupled Eulerian-Lagrangian (CEL)** method also attempts to capture the strengths of the Lagrangian and Eulerian methods. In general, a Lagrangian frame is used to discretize the moving structure while an Eulerian frame is used to discretize the fluid domain. The boundary of the Lagrangian domain is taken to represent the interface between the different domains. Interface models use the velocity of the Lagrangian boundary as a kinematic constraint in the Eulerian calculation and the stress from the Eulerian cell to calculate the resulting surface stress on the Lagrangian domain. This method is used for the class of problems, which involves large deformations.

In the present model in order to impart Eulerian characteristics to the mesh, though the part was earlier defined as Eulerian, an extra partition was made on the rectangular soil domain. This region was assigned as a **void**. This helps in providing a path for the soil element to move after deformation.

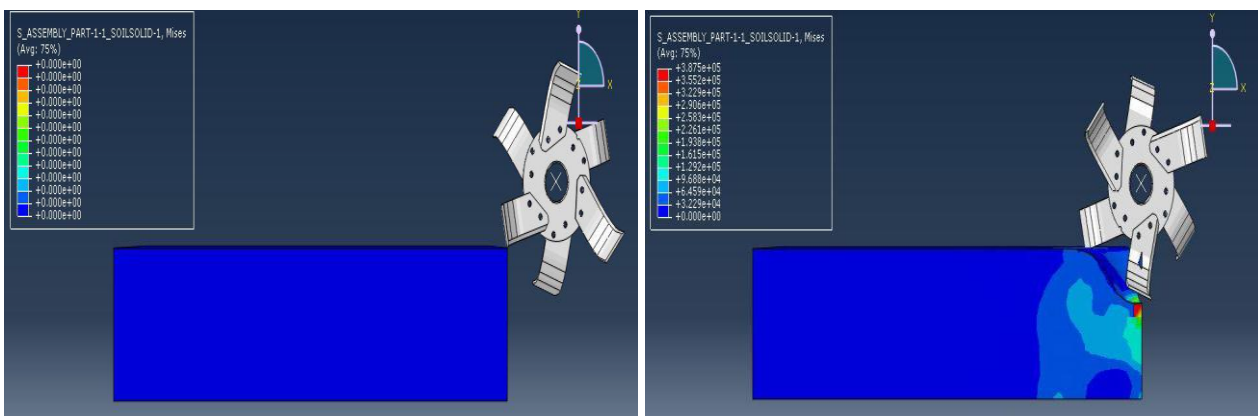
C. Element Death:

If material is added to (or removed from) a system, certain elements in your model may become "existent" (or "nonexistent"). The element birth and death options can be used to deactivate or reactivate selected elements in such cases. This feature is generally used in analyzing excavation (as in mining and tunneling) and staged construction in which one can easily identify activated or deactivated elements by their known locations.

Element death helps in removing only those elements from a meshed object which has failed. To achieve the "element death" effect, the program does not remove "killed" elements. Instead, it deactivates them by multiplying their stiffness (or conductivity, or other analogous quantity) by a severe reduction factor. Element loads associated with deactivated elements are zeroed out of the load vector. Similarly, mass, damping, specific heat, and other such effects are set to zero for deactivated elements. The mass and energy of deactivated elements are not included in the summations over the model. An element's strain is also set to zero as soon as that element is killed.

Density	1760 [kg/m3]
Young's Modulus, E	6 [MPa]
Poisson's Ratio, $\nu$	0.4
Cohesive Strength	30 [KPa]
Soil friction Angle	23 [degrees]
Plasticity Model	Mohr-Coulomb

Table 1: Soil Model Properties.





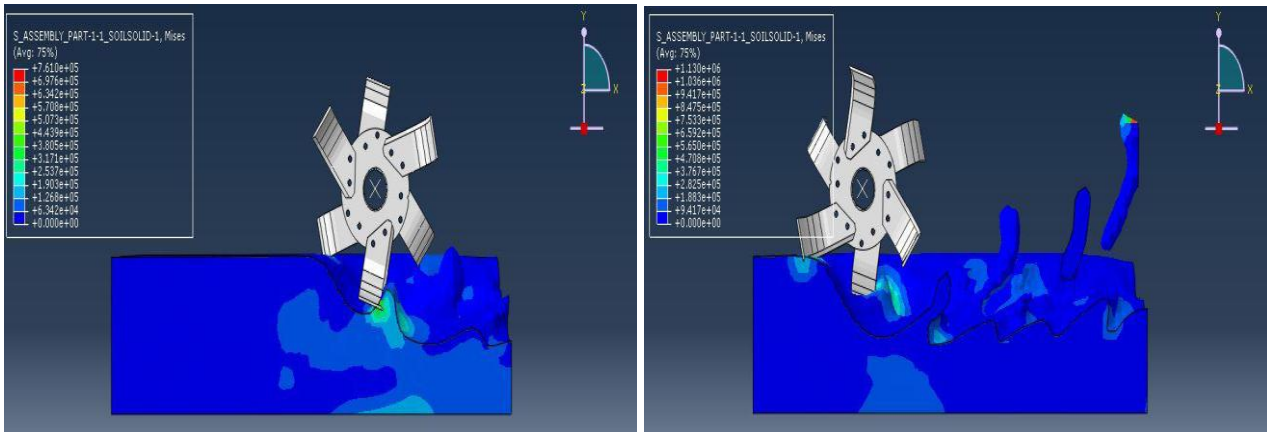


Figure 9: Simulation Of the Soil Cut Dynamics using Abaqus 6.13.

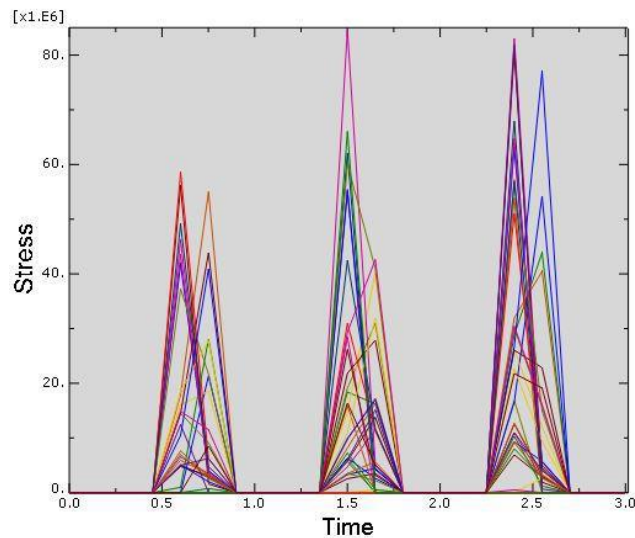


Figure 10: XY- Plot of the Contact Stress generated at a single blade tip face.

Simulation of the dynamic cutting action of rotary blades over soil model is completed. But the contour plot does not show values of deformation in the blade section. Hence XY plot options were used on the blade surface to obtain the time history plot of the Contact stress at the edge of the blade, by selecting the cutting face alone as the region of interest in the XY plot data settings.

A single blade cuts the soil 3 times during the period of simulations. It is shown by the 3 peaks separated by valleys of zero stresses. The peak value of these stresses occur as the cutting face of the blade just comes in contact with the soil surface. Hence in order to assess the static deformation of the blades it is sufficient to apply the peak stress from the plotted graph as input to the blade cutting face. It was obtained to be 75.667 MPa.

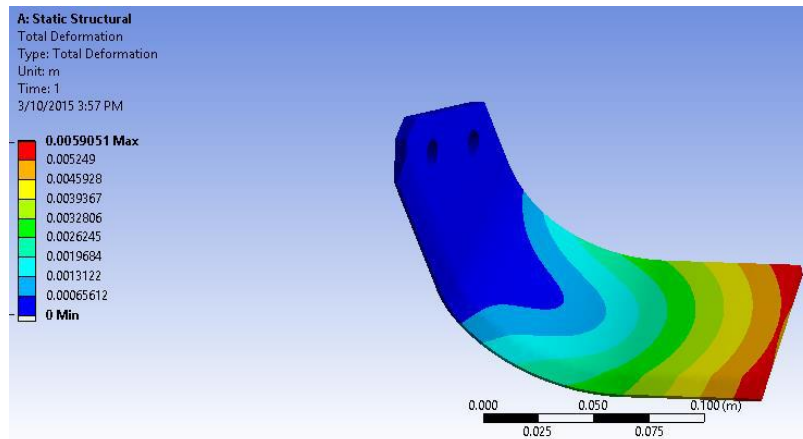


Figure 11: Contour Plot of the Deformation of a Single Blade at the point of first contact.

## VI. CONCLUSION

The complete 3-D modelling of a model of a 45 hp rotavator blade system has been completed using CREO PARAMETRIC 2.0. Kinematics of the Rotavator Blade motion was studied and the path traced by any point at the blade tip has been calculated and plotted. The blade characteristics such as Bite Length, Kinematic Parameter and Stagger Angle were studied. The dynamic analysis of rotavator blades during the tilling operation on soil is obtained using the FEA tool Abaqus. The simulation helped in understanding the nature of cut executed by the blade in the agricultural field. The deformation of a single blade was found to be minimum when the Blade angle increases to  $105^{\circ}$ .

.Using the same method as followed in this analysis, the nature of cutting using alternate blade shapes need to be studied, and the volume fraction of the soil cut to the uncut volume is to be compared to obtain the optimum blade profile for tilling purposes.

## ACKNOWLEDGMENT

I would like to thank Dr. Velamurali, Professor and Division Head of Engineering Design department, College of Engineering, Guindy for his valuable support to develop this project.

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