Optimization of Design Parameters for Rotary tiller's Blade

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Abstract—Tillage is an operation performed to obtain a desirable soil structure for a seedbed. A granular structure is desirable to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil and to minimize resistance to root penetration. 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). Nowadays, utilization of rotary tillers has been increased in agricultural applications because of simple structure and high efficiency for this type of tillage implements. By taking advantage of rotary tillers, the primary and secondary tillage applications could be conjugated in one stage. This results in a decrease in the number of machinery passes, causes a decrease overall costs for land preparation. However in a rotary tiller, blades are the main critical parts which engaged with soil to prepare the land. These blades interact with soil in a different way than normal plows which are subjected to impact and high friction which ultimately creates unbalancing and non uniform forces on the rotary tiller which results wearing of the blades as a whole. The continuous fluctuating impact of soil crust / clods / stone develops high stress areas on blade tip or blade critical edges. Therefore, it is necessary to optimize the design of blade so that these blades experience less stress thereby reduces the wear. Thus an "L" type blade for tractor drawn Rotary tiller or Rotavator was designed and developed. Computer Aided Design package for designing of the blade and ANSYS programming was used for the simulation and optimization of the blade. Based on the simulation results optimized design of blade through was suggested.

Keywords—Rotavator Blade; Rotavator; Tillage;, Rotary tiller; Seedbed

I. INTRODUCTION

A rotary tiller is a specialized mechanical tool used to plough the land by a series of blades which are used to swirl up the earth. Rotary tillers have become world famous for preparation of seedbed Rotary tillers have become world famous for preparation of seedbed in fields. These equipments are often used for breaking or working the soil in lawns, gardens, etc. [1]. Nowadays, utilization of rotary tillers has been increased in agricultural applications because of simple structure and high efficiency for this type of tillage implements. By taking advantage of rotary tillers, the primary and secondary tillage applications could be conjugated in one stage [2]. Despite of their high energy consumption, since rotary tillers have the ability of making several types of tillage applications in one stage, the total power needed for these equipments is low [3]. Because rotary tillers power is directly transmitted to the tillage blades, the power transmission efficiency in rotary tillers is high. Power to operate the rotary tiller is restricted by available tractor power [4-5].

Rotavators are mostly available in the size of 1.20 – 1.80 m working width and which is suitable for tractors having 45 hp and above. Further, rotavator may have 'L' shape, 'C' shape, 'J' shape, hook tines and straight knife blades to suit various operating conditions (Fig. 1). Generally, L-shaped blades are used in Indian rotavator. The work quality by using a rotavator not only depends on design parameters but rotor blade layout, speed of rotors, forward speed etc. which are significantly affects the machine performance. Depending on the soil conditions, blade geometry and velocity ratio, the interference of the backside of the blade and the uncut soil may result in severe soil compaction and high power consumption. This is the main reason to cause vibrations, which are a result of the reaction of soil upon the tiller blades. The proper design of the rotary tiller blades is essential to efficient operation [6]. The matrix equations for describing the motion of the blade of rotary tiller were described [7-8] which demonstrated that energy consumption in rotary tillage can be decreased through improved blade design. In maize and spring barley production systems in combination with a chisel plow, rotary tillers have been found to have high energy requirements, but rotary tilling is more effective in saving labor compared to conventional tillage systems [8]. The continuous fluctuating impact of soil crust / clods / stone develops high stress areas on blade tip or blade critical edges. A rotavator has a useful life of 2400 h (8 year) with annual use hour as 300.The local blades need replacement after 80-200 h of their use; however, imported blades need replacement after 300-350 h in normal soil. It is estimated that around 5 lakhs blades are required annually towards replacement and for new machines [9]. Therefore, proper design of these blades is necessary in order to increase their working life time and reduce the farming costs [10]. In India, because of variety of soil conditions in different regions, different blades are used, but most of the blades faces similar problem like high rate of wear which ultimately reducing the service life/working life. Working life time of the blades can be increased by a suitable design according to the soil type and soil condition. In India, because of variety of soil conditions in different regions, different blades are used, but most of the blades faces similar problem like high rate of wear which ultimately reducing the service life/working life. Working life time of the blades can be increased by a suitable design according to the soil type and soil condition. Hence, the object of this study was to design suitable rotary tiller blade design optimization using finite element analysis method to increase the useful life of the tiller blade in order to reduce the idle time required to replace the blade periodically during soil preparation.

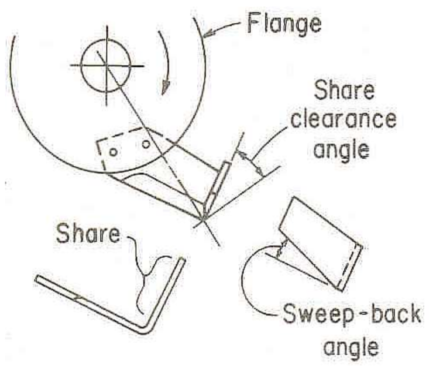


Fig. 1. Three views of an L-shaped blade for rotary tiller [11]

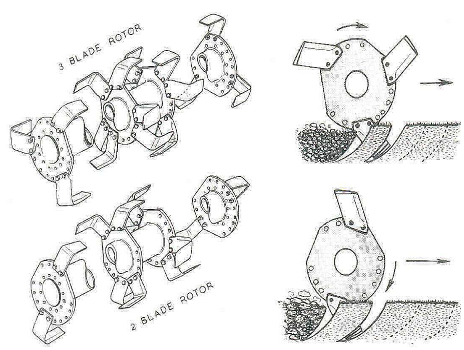


Fig. 2. Rotary tiller rotors with L-type blades showing methods of mounting and cutting action [3]

II. TILLAGE

Tillage may be defined as the mathematical manipulation of soil to develop a desirable soil structure for seedbed or root-bed, to control weeds, to manage plant residues, to minimize soil erosion and to establish specific surface configurations for planting, irrigation etc. Tillage operations for seedbed preparations are often classified as primary or secondary. Rotary tiller's or rotavators are being used now days as a secondary tillage implements as these tool obtain their energy in more than one manner, energy from a rotary source usually the tractor PTO. Reduced draft requirements and greater versatility in manipulating the soil to obtain a desired result are the two reasons for considering these more complex types of equipments. Rotary tiller is the perfect machine suitable for the minimum tillage system. The high degree of pulverization does make rotary tillers good seedbed preparation. Rotary tillers are also good for cutting up vegetable matter and mixing it throughout the tilled layer. Rotary tillers are widely used for rice in Japan (Kawamura, 1970) and other Asiatic countries. Rice paddies in these countries are often "puddled" by means of underwater rotary tillage. 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 as shown in Fig.3. 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.

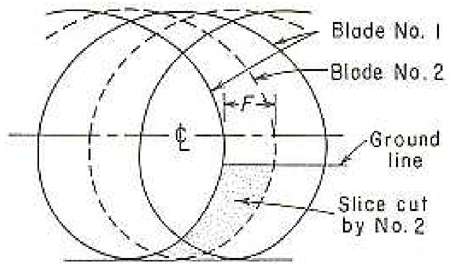


Fig. 3. Paths of cutting edges or tips for 2 blades 180^o apart, in relation to forward travel [11]

III. MATERIALS AND METHODS

To fulfill the objectives of the present study, initially a commercially available blade was selected. This blade generally used by the farmers of West Bengal and this blade is readily available. It is used in tractor mounted rotavator with 54, 60, 66 & 72 blades. Based on the available data and feedback from the users (Table 1), it has been found that the blade is worn out after certain hour (40-300 hrs) field usages depending on the soil conditions. This may be due to excessive load and stresses coming on the surface which exposed most part in the soil while in the field usage in a rotavator. The excessive loads and stresses caused wear of the blade tip or the cutting edges. Although the material used in the blade is having sufficient wear resistance properties, but the wear is taking place because of geometry/profile of the blade. Based on the geometrical configuration of the selected blade three more different types of blades were designed. All these four blades were analyzed to find out the maximum stresses/loads coming on to the working surface through ANSYS. Based on the results, best design of the blade was chosen which experience less stresses. The geometry and 3D model of the original blades has shown in Fig.4, whereas Fig.5 describes the important design parameters of a typical rotavator blade. Table 2 depicts the design parameters considered as input parameters in this study.

TABLE I. FIELD USAGE DATA OF COMMERCIALLY AVAILABLE "L" TYPE BLADE

Sr. No.	***Type of Blade***	***Soil Type***	***Hour of usage***
1	L	Laterite	40-50
2	L	Red soil	50-60
3	L	Terai soil	250-300
4	L	Sandy soil	150-200

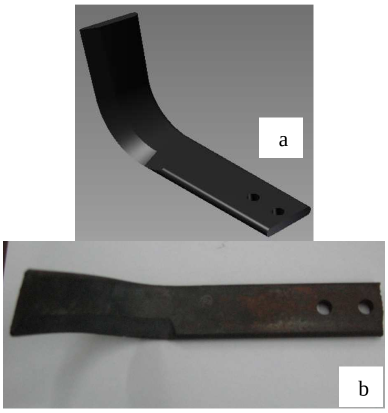


Fig. 4. a: Geometry (3D Model); b: Original Part of Blade-I

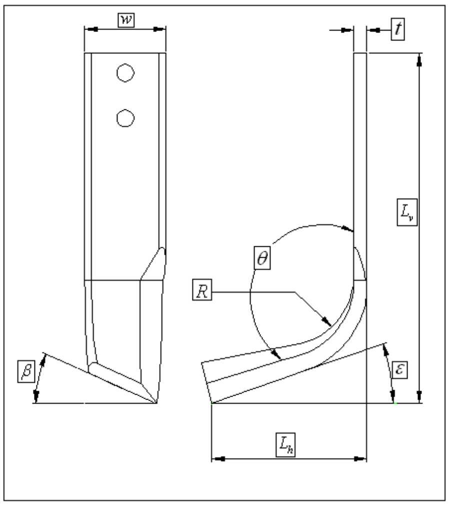


Fig. 5. Important design parameters of a typical rotavator blade

A. Blade Fabrication

Based on the above design parameters, Blade-II, Blade-III & Blade-IV were fabricated and these are shown in Fig.6.

TABLE II. PARAMETERS OF DIFFERENT BLADES DESIGNED FOR HE STUDY

Para-meters	***Notations***	***Blade***			
		I	***II***	***III***	***IV***
w	Blade span, mm	40	40	40	40
L_v	Effective vertical length, mm	212	197.5	205.5	216
L_h	Blade cutting width, mm	88.7	89.7	79	78.5
R	Curvature between L_v and L_h mm	40	35	45	50
θ	Blade angle, degree	108	100	105	115
β	Clearance angle, degree	20	25	22	28
t	Blade thickness, mm	8.0	8.0	8.0	8.0
ε	Bending angle, degree	22	22	22	22

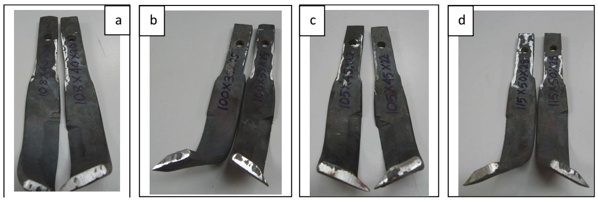


Fig. 6. Fabricated blades: a) Blade-I, b) Blade-II, c) Blade-III & d) Blade-IV

IV. CAD MODELLIG AND ANALYSIS

The three important steps in ANSYS programming used for CAD-modelling and analysis are Pre-processing, Solution & Post processing [12]. The same steps were followed in the current research work. The CAD model of the rotary shaft assembled with blades has shown in Fig.7.

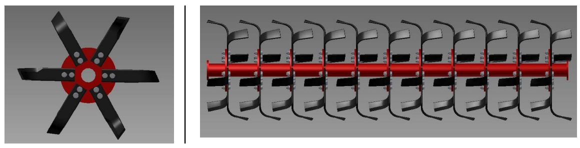


Fig. 7. CAD Model of Rotary shaft assembled with Blade

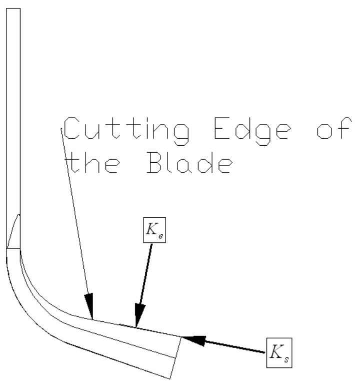


Fig. 8. Major Forces acting on a rotavator blade

ANSYS 14.0 was used in this study for static analysis and optimization of the blade. The loading and boundary conditions were shown in Fig. 8. Here soil force (K_e) acting perpendicularly on the cutting edges of each of the blades. The tangential forces aslo acts through tagent of the blade cutting edge. The boundary conditions are mainly similar to the fixing of the blades with the flanges on the drive shaft.

The following parameters were used during the analysis:

Blade design has been optimized considering that blade parameters are functions of operating parameters, soil parameters, and tool parameters. The draught requirement of any passive tillage implement D_i in N was found to be function of working depth d in m, travel speed V in km/h, width of the implement W_i in m, tool geometry characterised by angle α_i in degree and length L_i in m, and soil properties such as bulk density ρ_w in kg/m3 and cone penetration resistance R_c in kPa [13] and can be expressed as

$$D_i = f\left(d, V, W_i, L_i, \alpha_i, \rho_w, R_c\right)$$

The above equation can also be written as

$$D_i = f_1(d,V)\, f_2(W_i, L_i, \alpha_i)\, f_3(\rho_w, R_c)$$

Where f_1, f_2 and f_3 are functions related to operating parameters, implement geometry and soil conditions respectively [14]

In the similar way here, considering a 45 hp tractor for the rotavator tests following data are taken:

Tractor Power (N_c) = 45 hp,

Tractor forward speed (L1) = 0.7 m/s

Typical traction efficiency (η_c) = 0.8-0.9,

Coefficient of reservation of tractor power (η_z) =0.7-0.8,

The following are the parameters for Rotary tiller used in the study

work depth (a) = 100 mm,

work width (b) = 1600 mm,

Operating parameters which were considered during the static analysis are given below:

Rotor rpm = 206, Blade peripheral velocity = 5.6 m/s, Total number of blade = 66, Number of blades on each side of the flanges=11 and hence n_e = 11/66.

The soil force acting on each of the blades (K_e) is calculated by the following equation:

$$K_e = \frac{K_s C_p}{i Z_e n_e} \quad [15] \tag{1}$$

Where, K_s is the maximum tangential force (kg), C_p is the coefficient of tangential force, i is the number of flanges, Z_e is the number of blades on each side of the flanges, and n_e is obtained through division the number of blades which action jointly on the soil into the total number of blades. For designing blade, the maximum tangential force which can be endured by the rotor should be considered. The maximum tangential force occurs at the minimum of blades tangential speed is calculated by the following [15]:

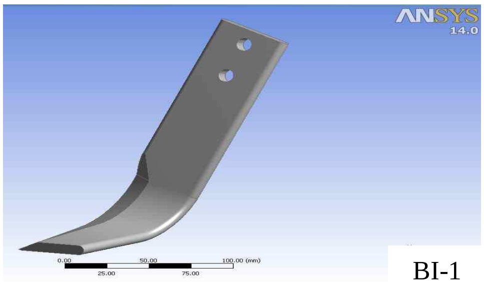
$$K_s = C_s \frac{75 N_c \eta_c \eta_z}{u_{\min}} \tag{2}$$

Where, C_s is the reliability factor that is equal to 1.5 for non-rocky soils and 2 for rocky soils [15]. Based on the above parameters including the design parameters as detailed in section 5.0 and using the equations 1 and 2 we get,

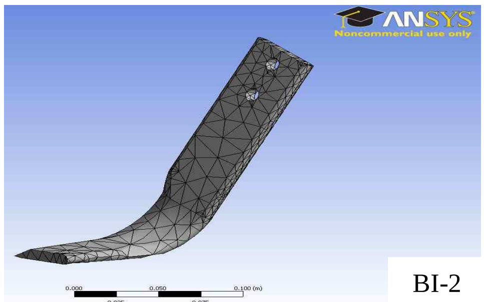
K_s = 2083 kg and K_e = 378 kg = 3800 N. These values were used in the analysis by ANSYS. The results are presented in the following section.

V. ANSYS RESULTS

Blade-I: The results for the deformation and Von mises stress for this blade are represented here.

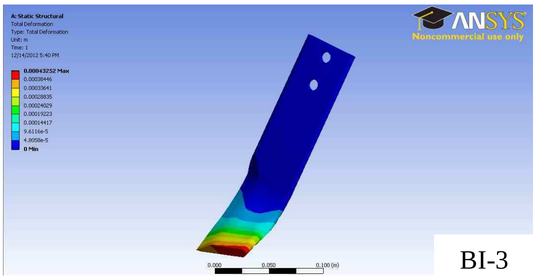


BI-1

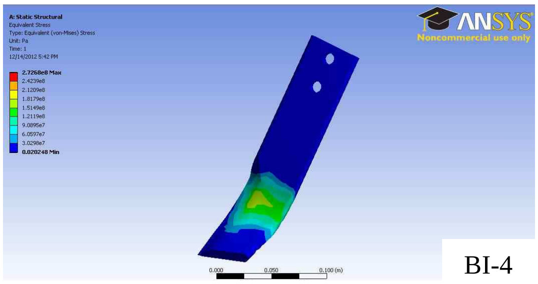


BI-2

Fig. 9. Analysis results for Blade-I (BI-1: 3D Model; BI-2: Meshing)



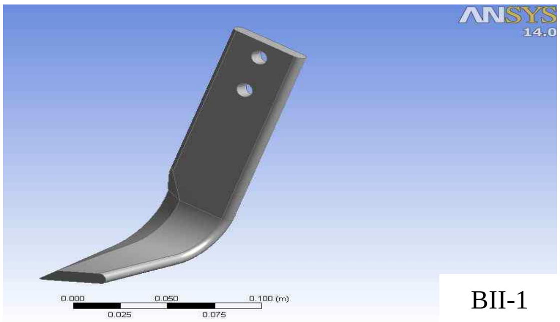
BI-3



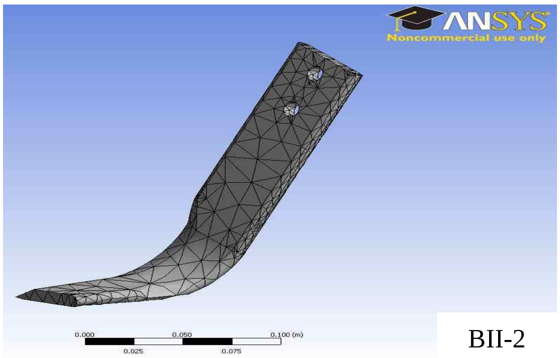
BI-4

Fig. 10. Analysis results for Blade-I (BI-3: Deformation; BI-4:Von mises Stress)

Blade-II: The results for the deformation and Von mises stress for this blade are represented here.



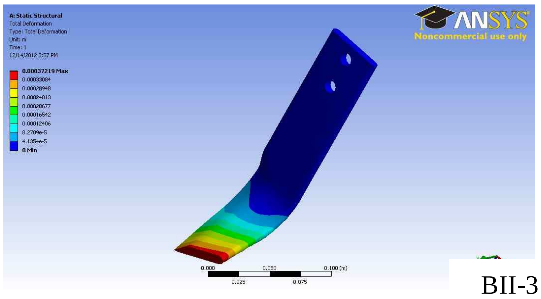
BII-1



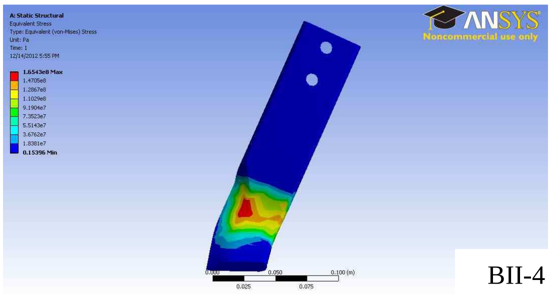
BII-2

Fig. 11. Analysis results for Blade-II (BII-1:3D Model; BII-2:Meshing)

Material properties used in the analysis are presented in Table 3. Figs.9-16 shows the results of analysis in graphical mode for the Blade-I, Blade-II, Blade-III & Blade-IV respectively.



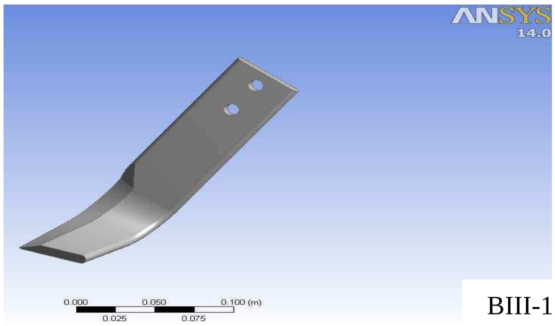
BII-3



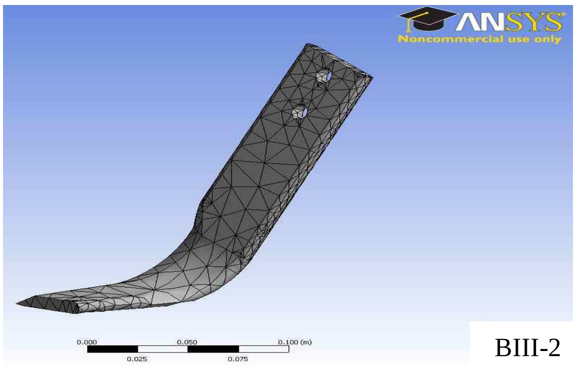
BII-4

Fig. 12. Analysis results for Blade-I (BII-3: Deformation; BII-4:

Blade-III: The results for the deformation and Von mises stress for this blade are represented here.



BIII-1

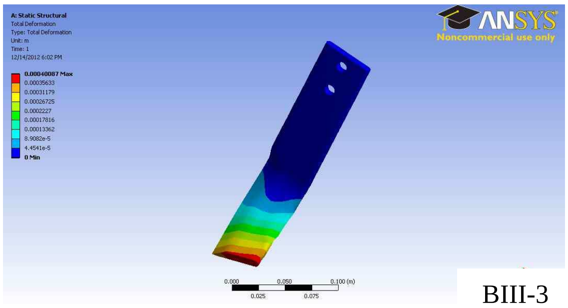


BIII-2

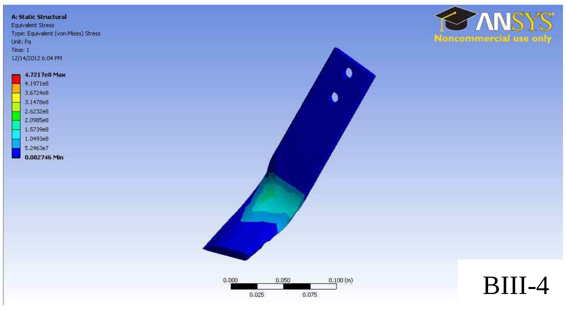
Fig. 13. Analysis results for Blade-III (BIII-1:3D Model; BIII-2:Meshing)

TABLE-III MATERIALS PROPERTIES

Young's Modulus, Pa	*Poisson's Ratio*	*Bulk Modulus, Pa*	*Shear Modulus, Pa*	*Compressive Yield Strength, Pa*	*Ultimate Tensile Strength, Pa*
2.e+011	0.3	1.6667 e+011	7.6923e+ 010	2.5e+008	4.6e+008



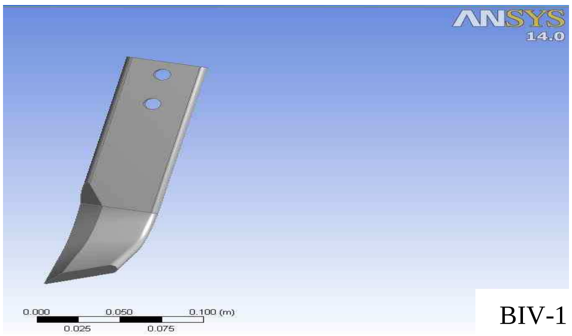
BIII-3



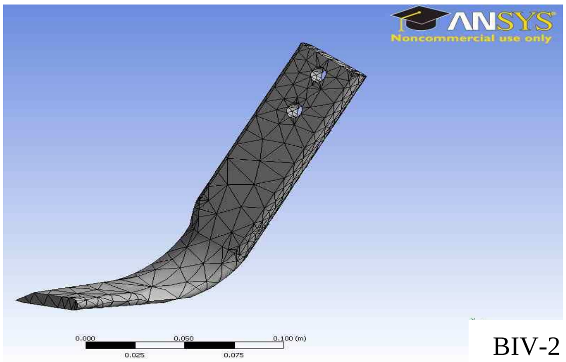
BIII-4

Fig. 14. Analysis results for Blade-III (BIII-3:Deformation; BIII-4:Von mises Stress)

Blade-IV: The results for the deformation and Von mises stress for this blade are represented here.



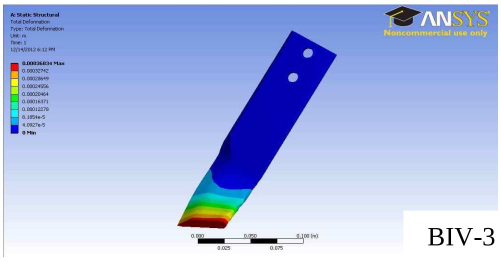
BIV-1



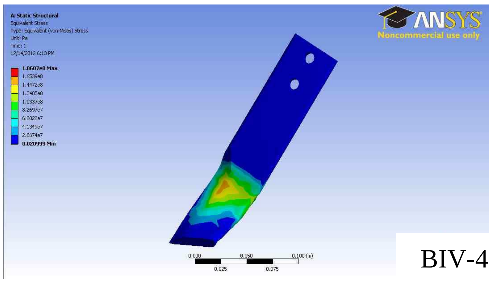
BIV-2

Fig. 15. Analysis results for Blade-IV (BIV-1:3D Model; BIV-2:Meshing)

The resulted has been computed and the comparison presented in Table 4. The results show that maximum stress is coming on the blade-III while the lowest is on the blade-II. At the same time, maximum deformation is achieved for the blade-III and lowest for the blade-IV. The blade–II is also faces with deformation near to the deformation of blade-IV, but stress value is minimum for



BIV-3



BIV-4

Fig. 16. Analysis results for Blade-III (BIV-3:Deformation; BIV-4:Von mises Stress)

the blade-II. So, the optimized blade should be similar to blade-II. Hence the optimization results a blade similar to the geometry of blade-II.

TABLE-IV COMPARISON OF RESULTS

Sl No.	*Blade type*	*Soil force acting in the blade, K_e, N*	*Maximum Deformation, mm*	*Von mises stress, Pa*
1	Blade-I	3800	0.38446	$2.7268x10^8$
2	Blade-II	3800	0.37219	1.5654310^8
3	Blade-III	3800	0.40087	$4.7217x10^8$
4	Blade-IV	3800	0.36834	$1.8607x10^8$

VI. CONCLUSIONS

Finite element is an effective tool for investigation of stress analysis in components. Rotary tillers are primary tillage tools which used for solving the hardpan problems in the agricultural lands. This research focuses on the design optimization of rotary tillers blade with four different shapes. Results showed that shape of blade has significant effect in the maximum deformation and stress of a particular blade. According to the results, L shape Blade-II facing lower stress than the other types. It shows that L shape has better design than the others and this makes the higher factor of safety for L shape blade and consequently makes it's more working life. This paper presents a theoretical method for rotary tillers design. The results of this study should be verified by further field trials on rotary tillers according to the results offered in this paper.

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