Rotary Tiller's Blade Design using Finite Element Analysis (FEA)

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Abstract: *The continuous increase in fossil fuels price has resulted substantial and tremendous increase in the cost of land preparation. This has direct effect on the food pricing which in turns results in considerable increase in the cost. The situation is worsened by the prevalent use of the conventional tillage system in the preparation of seedbeds, particularly for deep tillage. This system of tillage escalates land preparation costs because it requires a series of operations using passive tillage tools to realize an acceptable tilth quality. It also ties down capital in the form of additional machinery and tillage tools; thus increasing significantly the cost of land preparation. Rotary tiller is a most suitable tillage machine designed for seedbed preparation. Blades are the main critical parts of a rotary tiller, which are 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. This paper aims at design optimization of rotary tiller blades using modern tools like FEA.*

Keywords: *rotavator, CAD/CAM, 3D Model, FEA, bite length, kinematic parameter*

1. INTRODUCTION

Rotary tiller is a tillage machine designed for preparing land suitable for sowing seeds (without overturning of the soil), for 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. 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. It can be adjusted according to the specific requirements of the soil. If the soil requires being crumbled to very fine density, it can be achieved by virtue of adjusting the trailing board to give maximum tillage. 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 (Hendrick & Gill, 1971c). 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 (Topakci *et al.*, 2008). Therefore, the agricultural soil could be prepared with only one cross of this type of tillage implements from the land. This results in a decrease in the number of machinery passes on the land and subsequently, causes a decrease in the soil compaction which could be obtained due to the excessive equipments crosses from the land. 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 (Culpin, 1981). 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 (Yatsuk *et al.*, 1981; Srivastava *et al.*, 2006).

In the past, a number of studies were conducted to evaluate the performance of rotary tillers. Rotary tillers perform well in suitable soil conditions but consume high amounts of energy. To improve their adaptability, an effort is required to investigate what kind of alternatives can be undertaken to heighten the efficiency of the rotavators. (Kosutic et. al., 1994).

The continuous fluctuating impact of soil crust or clods or stone develops high stress areas on blade tip or blade critical edges. The blades of a rotavator also work at an angle, thus overcoming the possibilities of blockages and ensuring that no residue is left stuck on the blades. However, the rotary tiller blades interact with soil in a different way than normal plows. These blades 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 (Saxena and Singh, 2010). Rotary tillers' blade usually works in the very arduous conditions, so they bear heavy dynamic loads. Therefore, proper design of these blades is necessary in order to increase their working life time and reduce the farming costs (Mollazade et al., 2010). 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 four different types rotary tiller blade and choose best of them by design optimization using finite element analysis method.

2. FINITE ELEMENT METHOD

The following are the three basic features of the finite element method (Reddy, 1984):

  i.   Discretization of the given domain into a collection of preselected finite elements.
  ii. Derivation of element equations for all typical elements in the mesh
  iii. Assembly of element equations to obtain the equations of the whole problem
  iv. Imposition of the boundary conditions of the problems
  v.   Solution of the assembled equations
  vi. Post processing of the results

Finite Element (FE) is one of those methods which used for evaluation of a structure under static and dynamic loads before making the main model. This leads to improve the strength of our design. ANSYS is a general purpose software package based on the finite element analysis. This allows full three-dimensional simulation without compromising the geometrical details (Hughes 2000; Madenci and Guven 2007). Finite element method was used by many researchers in order to design the tillage tools or investigate the interaction between soil and tillage implement. Most investigation used a blade as the object studying the interaction between soil and tool, because its geometric simplicity made the corresponding FEM analysis relatively easier (Shen 1998; Yang and Hanna 1997; Mouazen and Nemenyi, 1999; Araya and Gao, 1995; Godwin and Spoor, 1977).

3. MATERIALS AND METHODS

To fulfill the objectives of the present study blades with different geometrical configurations were selected. Based on assumed literature survey and previous works, four different types of blades were designed. The material used was high carbon steel for the tillage tool i.e. blade material.

Based on the work reported by many previous researchers, it has been found that the blade is worn out after few hour field usage. This may be due to excessive load/stresses coming on the surface which exposed most part in the soil while in the field usage in a rotavator. The excessive loads/stresses caused wear of the blade tip/cutting plane. Although the material used in the blade is having sufficient wear resistance properties, but the wear is taking place because of geometry and profile of the blade. Thus initially a commercially available blade was selected. Based on the geometrical configuration of the selected blade, three more different types of blades were designed. These four blades were analyzed to find out the maximum stresses/loads coming on to the working surface through ANSYS. From the analysis results, design optimization was carried out to choose the best design out of the four selected blade.

Thus, an "L" type standard blade was selected and designated as Blade-I. This blade was modelled using 3D CAD software as shown in Fig.1. The important design parameters of this blade is shown in Fig.2. Later on analysis was done using field trial data available from the manufacturer and farmers. Based on the results of analysis, three more different blades were designed, these were designated as Blade-II, Blade-III & Blade-IV. These were again analysed using ANSYS software. After the analysis, based on the results of the four different blades, design optimization was done and the optimized design was selected. These results are presented in this section. Table1 represents the different design data for the four blades Blade-I, Blade-II, Blade-III & Blade-IV.

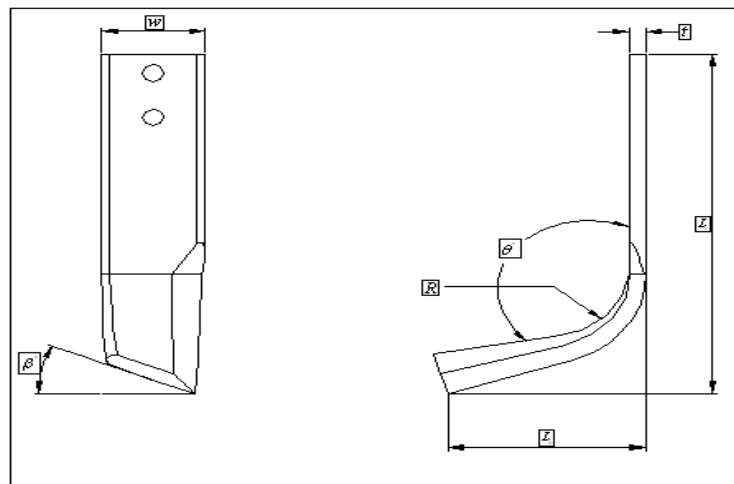**Fig1.***Geometry (3D Model) of Blade-I & the Original Part (Blade-I)*

Fig2.*Important design parameters of L type blade*

Table1. *Parameters of different blades designed for the study*

Param-eters	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	21.6
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

4. CAD-MODELING AND ANALYSIS IN THE PRESENT WORK

The three important steps in ANSYS programming used for CAD-modelling and analysis are Pre-processing, Solution & Post processing (Shinde et al. 2011). The same steps are followed here.
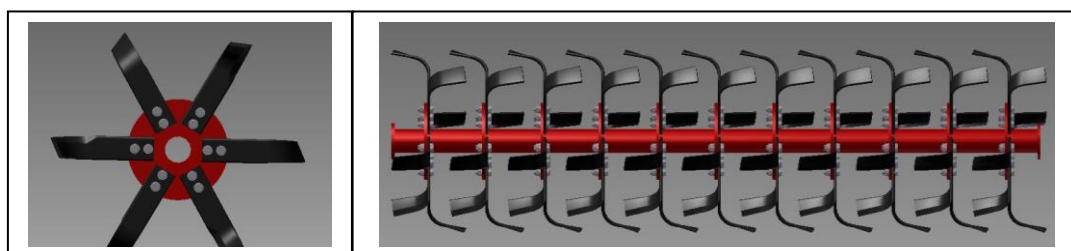

Fig3.*CAD Model of Rotary shaft assembled with Blade*

The CAD model of rotary shaft assembled with L type blade is shown in Fig.3. ANSYS 14.0 was used in this study to analyze and optimize the blade. The following parameters were used during the analysis:

Tractor Power (N_c)= 45 hp, Traction efficiency (η_c) = 0.8-0.9, Coefficient of reservation of tractor power (η_z) =0.7-0.8, Rotary tiller work depth (a) = 100 mm, Rotary tiller work width (b) = 1600 mm, Tractor forward speed (L1) = 0.7 m/s, Rotor rpm = 206, Blade peripheral velocity = 5.6 m/s, Total number of blade each type = 66, Number of blades on each side of the flanges=11, n_e = 11/66.

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

$$K_e = \frac{K_s C_p}{i Z_e n_e} \quad ((\text{Bernacki } et\ al., 1972) \tag{1}$$

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 (Bernacki *et al*., 1972):

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

Where, C_s is the reliability factor that is equal to 1.5 for non-rocky soils and 2 for rocky soils (Berbacki *et al*., 1972). Based on the above parameters including the design parameters as detailed in section 5.0 and using the equations 1&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.

5. ANSYS RESULTS

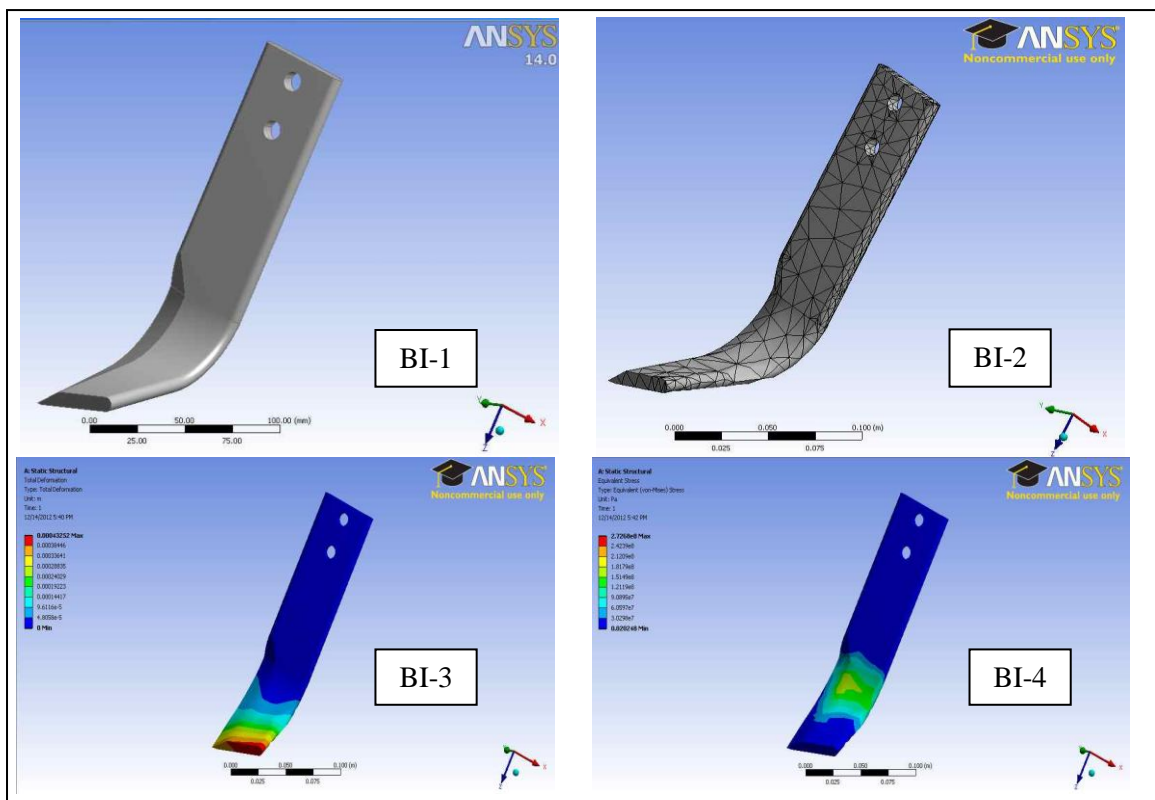Blade-I: The results for the deformation and Von mises stress for this blade are represented here.

Fig4.*Analysis results for Blade-I (BI-1: 3D Model, BI-2: Meshing, BI-3: Deformation and BI-4: Von mises stress)*

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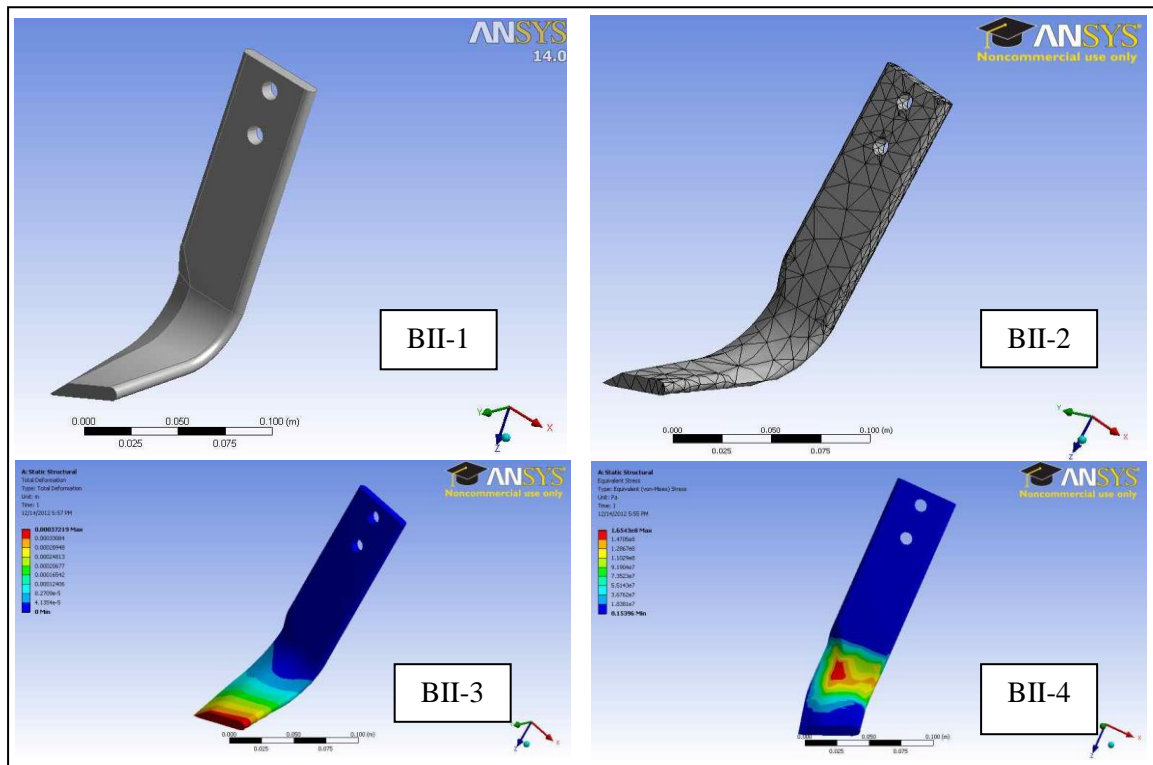

Fig5. *Analysis results for Blade-II (BI-1: 3D Model, BII-2: Meshing, BII-3: Deformation and BII-4: Von mises stress)*

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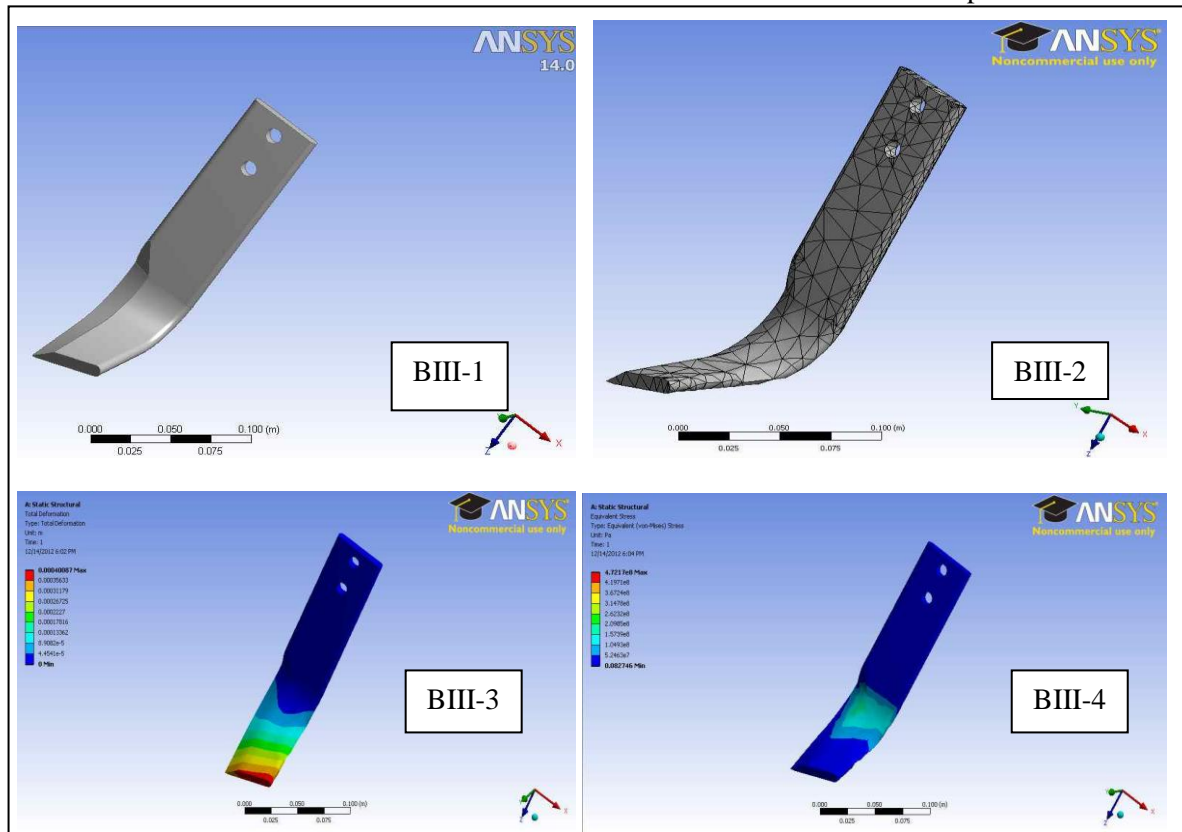

Fig6. *Analysis results for Blade-III (BIII-1: 3D Model, BIII-2: Meshing, BIII-3: Deformation and BIII-4: Von mises stress)*

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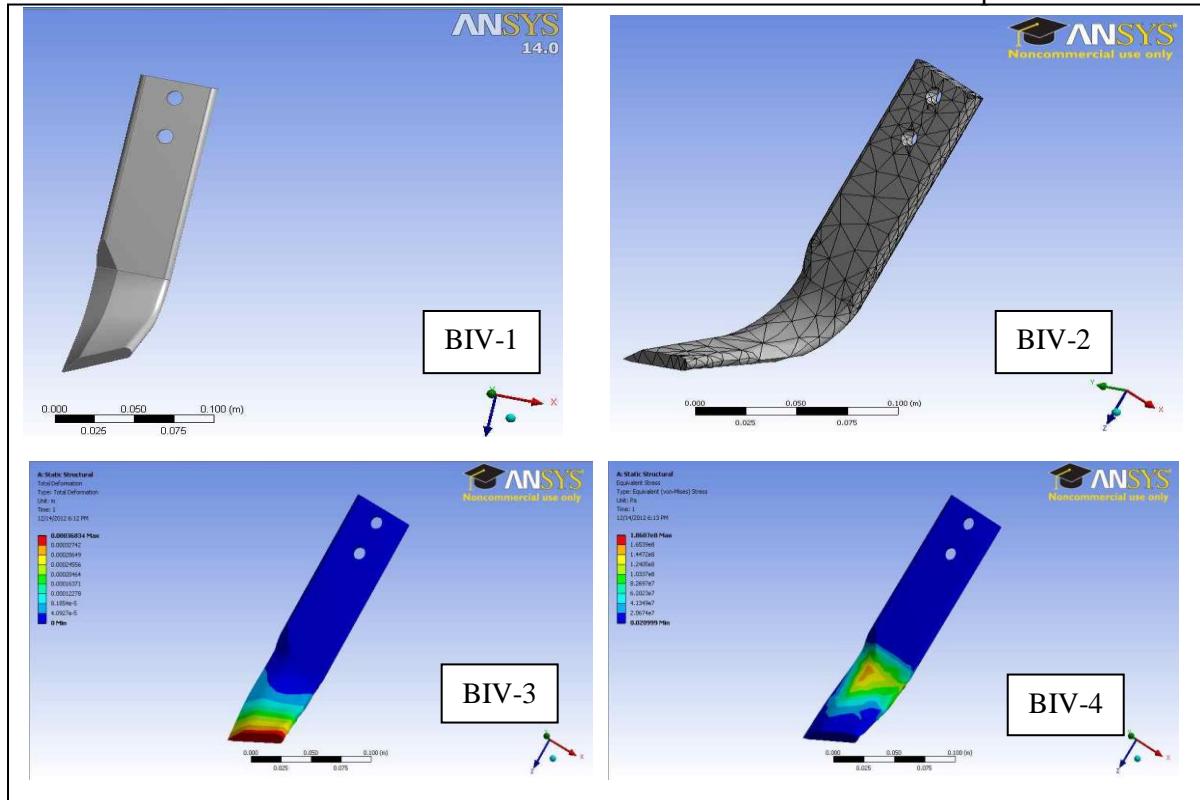

Fig7._Analysis results for Blade-IV (BIV-1: 3D Model, BIV-2: Meshing, BIV-3: Deformation and BIV-4: Von mises stress)_

Material properties used in the analysis is presented in table2. Fig.4-7 shows the results of analysis in graphical mode for the blade-I, blade-II, blade-III & blade-IV respectively. The resulted has been computed and the comparison presented in table3. The results shows 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 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.

Material: **Structural Steel Table 2:**_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	1.6667e+011	7.6923e+010	2.5e+008	4.6e+008

Table3._comparison of results_

Sl No.	Blade	Soil force acting in the blade, N	Maximum Deformation, mm	Von mises stress, Pa
1	Blade-I	3800	0.38446	2.7268×10^8
2	Blade-II	3800	0.37219	$1.56543 10^8$
3	Blade-III	3800	0.40087	4.7217×10^8
4	Blade-IV	3800	0.36834	1.8607×10^8

6. CONCLUSION

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 not significant roll in the maximum number of allowable force exertion cycles which caused to fracture of 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 tests on rotary tillers according to the results offered in this paper.

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