Comparative Analysis of Rotavator Blade for Rocky and Non-Rocky Soils

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Abstract - This paper presents stress analysis of rotavator blade for the rocky and non-rocky soil. We have selected L-shaped blade for the study because L shape is usually superior to others in heavy trash. They are better for killing weeds. Rotavators work in the very difficult conditions, so they bear heavy dynamic loads. Therefore, proper design of these equipment is necessary to increase their working life time and reduce the farming costs. For the study we have selected A 15 HP Mahindra Yuvraj 215 tractor and Shaktiman SRT 2.5 mini rotavator. We calculated Forces acting on each blade for rocky and non-rocky soil. After modeling of blade, we applied boundary and loading conditions on the models. Finally, models were analysed with analysis software. Analytical as well as software results showed that blade experiences less equivalent stress in non-rocky soil as compared to rocky soil. Results of this research can help the designers of rotavator blade to make similar works in their designs and increase the working life of blade.

Keywords- *Roavator Blade, Finite Element Method, Rotary Tillage*

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I. INTRODUCTION

Tillage has been defined as those mechanical, soil-stirring actions carried on for the purpose of nurturing crops. The goal of proper tillage is to provide a suitable environment for seed germination, root growth, weed control, soil-erosion control, and moisture control [1]. The objective of proper tillage is to provide a suitable environment for seed germination, root growth, weed control and soil-erosion control. Tillage is done mainly to loosen the upper layer of soil to create seedbed, to mix the soil with fertilizer and to remove weeds [2]. As a result of this processing the water-air, thermal and nutrient regimes of the soil are improved in the interest of the growth and development of crops.

A rotavator is power-driven cultivating equipment that breaks the soil with the help of rotating blades. The rotary tiller can be self-propelled and driven forward on wheels. Featuring a gearbox, the rotary tiller enables one to increase the rotation speed of the blades more than the forward speed of the equipment. This equipment's are often used for breaking or working the soil in lawns, gardens, etc. Electric rotary tillers are commonly used in gardens and fields. 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. Therefore, the seedbed could be prepared with single pass of this type of tillage equipment. 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 equipment's 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 equipment is low[3]. Because rotary tillers power is directly transmitted to the tillage blades, the power transmission efficiency in rotary tillers is high. Moreover, the negative traction existence in rotary tillers causes the required tractive force to be decreased and consequently, smaller tractors could be used with this type of tillage implements for land preparation. It offers an advantage of rapid seedbed preparation and reduced draft compared to conventional tillage. It saved 30-35 % of time and 20-25 % in the cost of operation as compared to tillage by cultivator. It gave higher quality of work (25-30%) than tillage by cultivator [4].

Rotary tillers are classified as active implements. In these machines, power is transferred to the tiller from the tractor via the power-take-off drive. A shaft containing blades is located at 90° to the line of travel and rotates in the same direction as the forward travel of the tractor [3]. Since the shaft turns at a rate that is considerably faster than the corresponding tractor speed, soil pulverization is accomplished. Power to operate the rotary tiller is restricted by available tractor power [5].

Rotary Tiller or rotavator is a highly effective machine for intensive tillage. It is one of the most efficient tillage systems when looking for solutions to specific soil tillage problems. No matter the soil type, soil conditions or the amount of residue, Rotavating will always produce the best result. The Rotavator can be easily adjusted for various working depths and soil finishes. The rotating blades chop and mix the residues evenly throughout the working depth, outperforming any other implement [3].

Blades are the active part of rotavator which directly in contact with soil. Most of the blades faces similar problem like high rate of wear which ultimately reducing the service life. Working life time of the blades can be increased by a suitable design according to the soil type. Thus, proper design of these blades is necessary in order to increase their working life time and reduce the farming costs. Therefore main objective of this study was to check that whether same blade is capable for tilling the rocky as well as non-rocky soil or not.

A. FINITE ELEMENT ANALYSIS

Finite Element Analysis (FEA) is a modern tool for numerical stress analysis, which has the advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties. 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. 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 [6].

B. BLADE DETAILS

Blades are the active part of rotavator which directly in contact with soil. The life of local blades is 80-200 hrs. and 300-350 hrs. of imported blades. It is estimated that around 5 lacks blades are required annually towards replacement [8]. Most of the blades faces similar problem like high rate of wears 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. Therefore, proper design of these blades is necessary in order to increase their working life time and reduce the farming costs.

A good blade should have the following qualities:

- transfers the maximum power from the rotor to the soil;
- produces the best seedbed;
- has the maximum working life;
- buries vegetation and trash as it cuts through the soil;
- Prevents weed binding on the rotary shaft.

These desirable qualities may be achieved by suitable design combination of the eight factors listed above [7].

Based on the market survey and available literature, it was found that generally three types of blades are used in a rotary tiller or rotavator as shown in fig 1. These are "L" shape, "C" shape, & "J" shape, to suit various operating conditions. L-shaped blades are better than C or J type blades in trashy conditions as they are more effective in killing and they do not pulverize the soil as much. It has been shown that the L blade requires more power but gives the greatest forward thrust to the vehicle on which it is fitted. In India, L-shaped blades are mostly used in Indian rotavator which are normally mounted with three right handed and three left handed blades per flange [3].

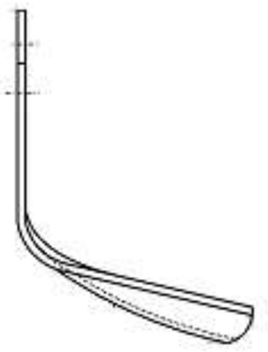
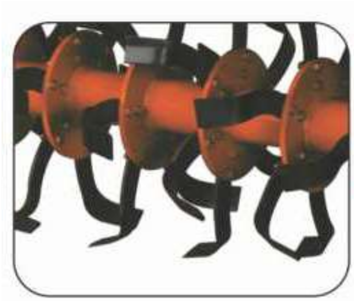


Fig.1 (a) L- shaped blade

(b) Rotor with C shaped blade



(c) Rotor with J shaped blade

II. Material and Methods

For the design of rotary tiller's blade we have selected the Mahindra Yuvraj 215 tractor and rotavator was Shaktiman SRT-M 2.5 miniseries. For this work we used L-shaped blade and the material for the blade was High Carbon steel and its properties are shown in the Table I. Technical specification of tractor and rotavator are given in table II.

TABLE I. SPECIFICATION OF HIGH CARBON STEEL

Specification	Value
Yield stress (MPa)	392
Elasticity modulus (GPa)	197
Poisson's ratio	0.29

A. Modeling And Meshing

Modeling of rotavator blade is carried out in CAD software CATIA V5. We drafted the design in sketcher module with the available dimensions of blade. Modeling was finalized in part design workbench. For analysis we used analysis software. After preparing a solid geometry model we import geometry file in analysis software. The important steps in analysis software are meshing and applying loading and boundary conditions in the preprocessor in order to get a solution. Then results will be generated in the post-processor. The element type was SOLID187 (3D, 10-Node Structural Solid). For meshing we used free mesh. The size of finite model was approximately 34786 elements and 54856 nodes for blade. Meshed model is shown in the figure 2.

Table II - Input parameters for design and analysis

Parameter	Symbol	Values
Rotary tiller work depth (mm)	b	100
Rotary tiller work width (mm)	a	800
Total number of blade	N	16
Number of blades on each side of the flange	Ze	4
No. of Flanges	i	4
Prime mover forward speed (m/s)	v	0.5667
Number of blades which action jointly on the soil into the total number of blades,	ne	¼
Prime mover Power (hp)	Nc	15
Traction efficiency	η_c	0.9
Coefficient of reservation of tractor power	η_z	0.75
Coefficient of tangential force	Cp	2

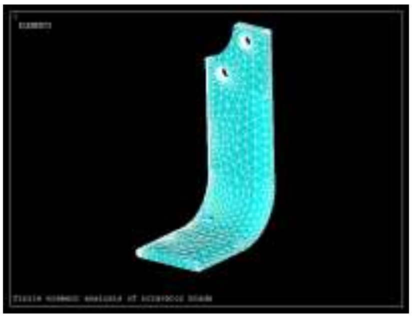


Fig. 2 Meshed models of L shape blade

B. Boundary and Loading Conditions

We have fixed the holes of the blade which provide the facility to connect the blade to the rotor. This makes the blade to not able to move or rotate in any directions.

In order to find the soil force acting on the blade and shaft of rotavator, following method was used:

C. Soil force acting on each blade and equivalent stress calculation

The maximum tangential force acting on the shaft was calculated by the following formula [9]:

$$Ks = C_s \frac{75\ Nc\ \eta c\ \eta z}{umin} \qquad \text{kg}$$

Where, Ks is the maximum tangent forces at the rotor axle in kg; u_{min} is the minimum linear velocity of rotor in m/s;Cs is the reliability factor that is equal to 1.5 for non-rocky soils and 2 for rocky soils.

The soil force acting on each of the blades (Ke) was calculated by the following equation [9]:

$$K_e = \frac{K_s \times C_p}{iZ_e n_e} \qquad \text{kg}$$

Where: Ks is the maximum tangential force (kg), Cp is the coefficient of tangential force, i is the number of flanges, Ze is the number of blades on each side of the flanges, and ne is obtained through division the number of blades which action jointly on the soil into the total number of blades.

Considering the shape of the blades, the bending stress (σzg), the shear stress (τskt), and the equivalent stress (σzt) can be calculated by the following equations [9].

Bending stress,

$$\sigma_{zg} = 6\frac{k_e S}{b_e h_e^2} \qquad \text{kg/cm}^2$$

Shear stress,

$$\tau_{skt} = \frac{3K_e S_1}{\left(\frac{h_e}{b_e} - 0.63\right) b_e^2} \qquad \text{kg/cm}^2$$

Equivalent stress,

$$\sigma_{zt} = \sqrt{(\sigma_{zg}^2 + 4\tau_{skt}^2)} \qquad \text{kg/cm}^2$$

The dimensions of the blades are defined as the form presented in Figure 3. The values of be, he, Ss, S and S1 are considered equal to 0.8, 7, 11.3, 14.5 and 8 cm, respectively.

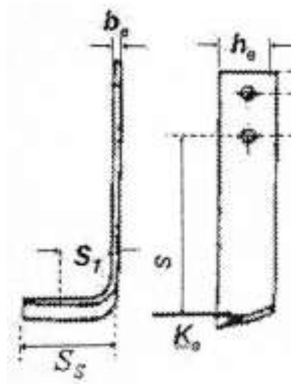


Fig. 3 Dimensions of the blade [11]

III. RESULT AND DISCUSSION

The analytical results of the maximum tangential force acting on the shaft (Ks), soil force acting on the each blade (Ke), bending stress, shear stress and equivalent stress were obtained for L shaped blade. It is observed that the maximum tangential force acting on the shaft (Ks), soil force acting on the each blade (Ke), bending stress, shear stress and equivalent stress were 3438.2163 N, 1719.104 N, 388.925 kg/cm^2, 1005.84 kg/cm^2 and 201.00 N/mm^2 for non-rocky soil and for rocky soil 4570.73 N, 2285.41 N, 517.044 kg/cm^2, 1344.82kg/cm^2 and 268.69 N/mm^2 respectively. While Von Mises stress acting on blade was 361.485 N/mm^2 for rocky soil and191.155 N/mm^2 for non-rocky soil (results are shown in fig. 4 and 5).

It is recommended that for the design of steel material and static loading condition the factor of safety is 1.5 to 2, based on the yield strength of the material [8]. We have considered the factor of safety for present case is 1.8, according to that allowable stress in present material is 217 N/mm^2. When we concentrate on the analytical as well software result it is clear that stresses acting on blade are more than allowable stress in case of rocky soil. And in case of non-rocky soil stresses acting on blade are less than allowable stresses so the blade is safe in only non-rocky soil.

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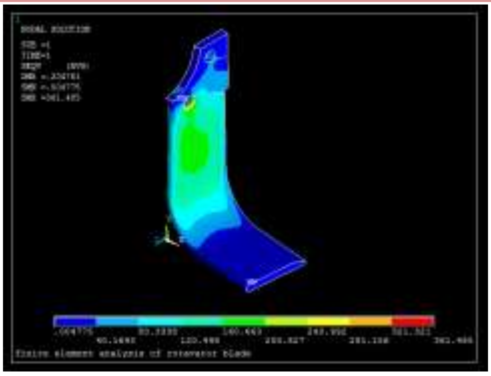

Fig.4 Stresses on blade in rocky soil

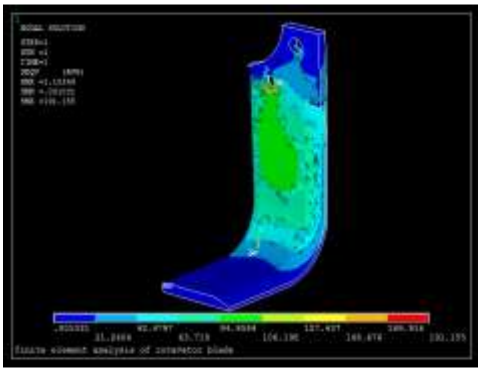

Fig. 5 Stresses on blade in non-rocky soil

IV. CONCLUSIONS

Blade experiences less stress when tilling the non-rocky soil comparing to tilling in rocky soil. When we use same blade in rocky soil it will fail during operation at the same time bade design is safe in non-rocky soil. It implies that different blades must be used for different soil quality. The combination of minimum speed (v) and minimum value of λ is obtained at first gear (heavy) so we suggest that the tractor should be operated on first gear (heavy).

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