Computer aided engineering analysis and design optimization of rotary tillage tool components

Gopal U. Shinde[1], Shyam R. Kajale[2]

(1. *Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Marathwada Agricultural University, Parbhani* (*M. S.*), *India*;

2 . *Shri Guru Gobind Singhji Institute of Engineering and Technology,Vishnupuri, Nanded* (*M. S.*), *India*)

Abstract: The computer aided engineering analysis and design optimization of rotary tillage tool on the basis of finite element method and simulation method is done by using CAD-software for the structural analysis. The different tillage tool parts of rotary tillage tools are geometrically constructed as a solid model. The actual field performance rating parameters along with boundary conditions are set in the software for 35 hp and 45 hp tractor. The estimated forces acting on soil-tool interface are fed into software as a loading condition. The resultant effects of loading condition on tillage blade and whole rotavator assembly were obtained from stress distribution and deformations plots. The proposed working results in identifying sufficient tolerance in changing the dimensions of rotavator frame sections and side gear box for removing the excess weight in a solid section and also to raise the weight of blade for a reliable strength. The present working model with tillage blade is analysed to new design constraints with change of its geometry for the maximum weed removal efficiency by presenting its practical results from the field performance.

Keywords: rotary tillage tool, simulation, FEM, design analysis, stress, deformation, rotavator

DOI: 10.3965/j.issn.1934-6344.2011.03.001-006

Citation: Gopal U Shinde, Shyam R Kajale. Computer aided engineering analysis and design optimization of rotary tillage tool components. Int J Agric & Biol Eng, 2011; 4(3): 1－6.

1 Introduction

Rotary tillage machine which is used in soil-bed preparation and weed control in arable field and fruit gardening agriculture. It has a huge capacity for cutting, mixing to topsoil preparing the seedbed directly. And also it has seven times more mixing capacity than a plough. Its components work under miscellaneous forces because of power, vibration, pointless, impact effect of soil parts as after reaching to higher side. The design optimization and manufacturing errors can be minimized by its components design analysis and optimization

Especially blades and transmission elements have to be reliable in the field performance against the operating forces. Predicting to stress distributions is so important for the designers, manufacturers and end users.

The design optimization of tillage tool is obtained by reducing its weight, cost and by improving a field performance to high weed removal efficiency. The computer aided design analysis by preparing a three-dimensional solid modeling and finite elements method applications are getting popular in the industry. Thus due to undesired stress distributions on its components, it cannot compensate to the operating forces i.e field environment and results in breakdown and failure due to higher stresses and deformation.

The proposed work develops a computer aided experimental system for design testing and valuation of

Received date: 2010-08-18 **Accepted date:** 2011-08-11

Biography: Shyam R. Kajale, PhD, Professor of Mechanical Engineering, Director, Shri Guru Gobind Singhji Institute of Engineering and Technology, Vishnupuri, Nanded (M. S.), India. Email: profsr.kajale@gmail.com.

Corresponding author: Gopal U. Shinde, Assistant professor of Mechanical Engineering, Department of Farm Machinery and Power, College of Agricultural Engineering and Technology, Marathwada Agricultural University, Parbhani (M.S.), India. Email:gopalushinde@gmail.com.

agricultural tools and equipments. The selected physical model of rotavator is measured with accurate dimensions and a solid (3-D) model is prepared in CAD-software such as Ansys, Catia, Pro-E, hypermesh etc. by assembling an individual part with detail specifications.

1.1 Rotavator

Rotary tiller is a tillage machine designed[1] 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[2]. 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. The Rotavator is the most efficient means of transmitting engine power directly to the soil with no wheel slip and a major reduction in transmission power loss[3].

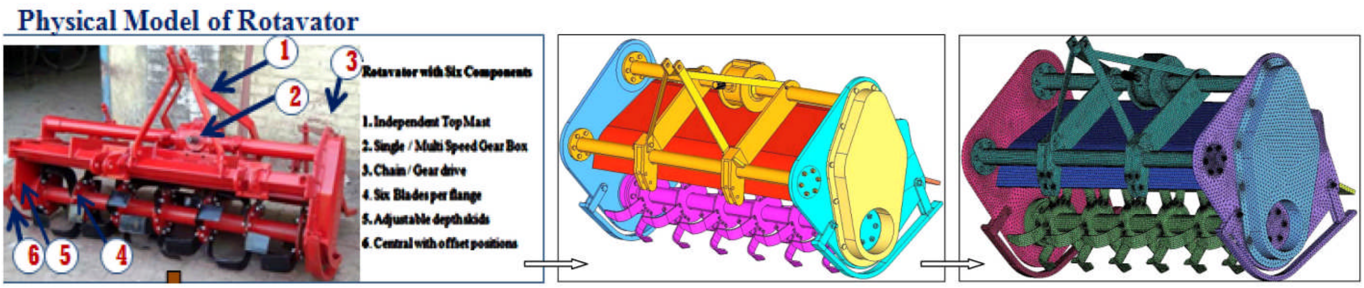
The Rotavator will produce a perfect seedbed in fewer passes. It is the ideal implement for cash crop farmers who need to bury and incorporate crop residues quickly, between crops. Tillage tools direct energy into the soil to cause some desired effect such as cutting, breaking, inversion, or movement of soil. Soil is transferred from an initial condition to a different condition by this process[4].

1.2 Rotavator assembly consist of following parts

1. Independent Top Mast 2. Single/Multi Speed Gear Box 3. Chain/Gear Cover Part Flange 4. Blades 5. Chain/Gear Cover Part 6. Frame and Cover 7. Adjustable depth skids 8. Offset adjustable frame

1.3 CAD model of rotavator

A solid view of CAD-model is prepared with accurate dimensions measured on physical model of rotavator as shown in Figure 1 below for the detail analysis.



Physical Model Solid Model Mesh Model

Figure 1 Computer aided modeling

1.4 Finite element method

The following are the three basic features of the finite element method[5]:

a) Division of whole into parts; which allows representation of geometrically complex domains as collection of simple domains that enable a systematic derivation of the approximation functions.

b) Derivation of approximations functions over each element; the approximation functions are often algebraic polynomials that are derived using interpolation theory[6].

c) Assembly of elements, which is based on continuity of the solution and balance of internal fluxes.

1.5 CAD-modeling and analysis

The three important steps in ANSYS programming used for CAD-modeling and analysis are: a) Preprocessing b) Solution c) Post processing. After preparing a solid geometry of rotavator the important steps are meshing and applying loading and boundary conditions in the preprocessor so that simulation can be run to get a solution and generate results in the post-processor.

1.6 Mesh generation (Meshing)

After validation of the model next step is generation of Finite Element Mesh. For the Rotavator SOLID45 elements are used for meshing[6]. A very fine mesh of freedom of the model increases. Hence a designer has to model it optimally i.e. placing fine mesh only at critical area; and coarse mesh at other. So that the run time is less and also the accuracy is not much affected (Figure 2).

1.7 Element description

1.7.1 SOLID 45

The solid meshing using SOLID-45 8 NODE 45 element, DOF: UX, UY, UZ Surface meshing by triangular 6 node element.

1) Element edge length–1.5 mm for crankshaft. Because in this crankshaft model chamfer width is 3 mm, so for better results. We can take two elements in this area.

2) Element edge length-2 mm for flywheel and Pulley.

1.7.2 BEAM 188

BEAM188 has six or seven degrees of freedom at each node using BEAM 188 element DOF: UX, UY, UZ and rotation RX, RY, RZ. The proposed work is taken for complete finite element analysis of rotavator tillage tool which introduces the use of CAD analysis for the first time in the design and development of Agricultural machines, tools and equipment.

1.8 Objectives

1) To prepare a geometric solid model of rotavator by using CAD-software.

2) To make the finite meshing by using meshing software.

3) To generate a CAD analysis report of rotary tillage tool components specifically for blade.

4) To compare existing design and identify the scope in design modifications in blade.

2 Materials and methods

2.1 Materials

The materials are taken from the manufacturing database of rotavator production system specification drawn by Industry. The material properties and soil properties are considered according to the following data[7] in the Appendix-II.

2.2 Soil parameters

The soil properties relevant to the design of rotavator were identified as soil type, moisture, bulk density and cone index[4]. The manners of measurement and characterization of these properties are discussed in the following sections. The experiment was conducted on black soil type. Moisture content of soil plays an important role for the growth of the crop hence following soil resistance and moisture content of soil are considered[8] as given in Appendix-III.

2.3 Element and node counts in FE-Model

Following table shows the total number of 2D and 3D elements obtained in FE model of rotavator.

2.4 Model analysis

The frequencies at which vibration naturally occurs, and the modal shapes which the vibrating system assumes are properties of the system, and can be determined analytically using Modal Analysis. The following table shows an idea about fundamental natural frequencies and higher natural frequencies in Hz. Section 4.1 contains the deformation plot for individual component and assembly for 10 different natural frequencies.

3 Results and conclusions

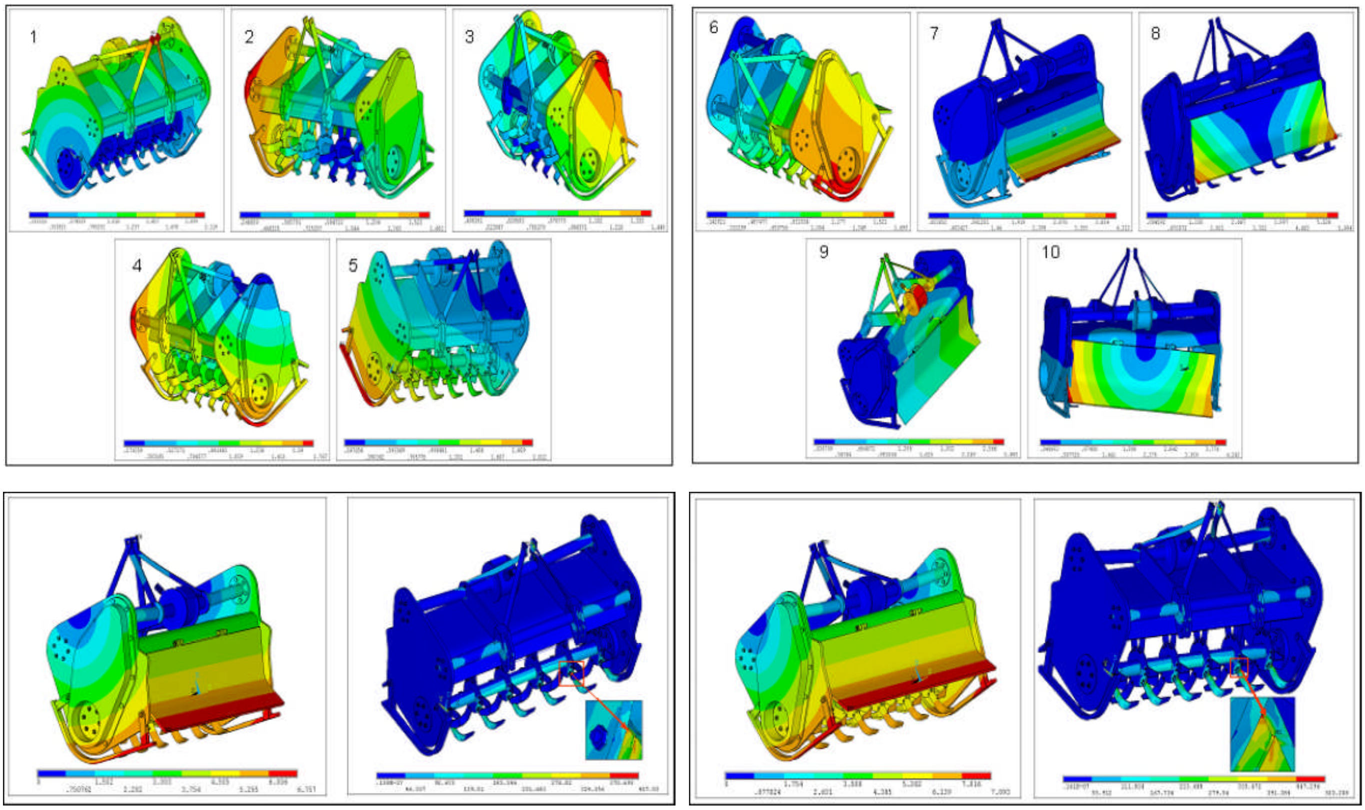
A rotary tillage tool such as Rotavator is designed[9] in computer aided design software. The rotary motion and soil surface interaction is considered with respect to the soil Vs. tillage tool dynamics by considering the following factors effecting the tillage operation such as tractor power (hp), maximum peripheral force (N), rotavator tyne velocity (m/s), tractor transmission efficiency (0.9 for concurrent revolution and 0.8-0.9 for reversed rotary), soil resistance to 0.7-0.8, radius of rotary (mm). The design analysis executed following results[10].

The following Figure 2 shows the Resultant stress and displacement for 35 hp and 45 hp tractors along with safety coefficients.

Maximum peripheral force on rotary blade 6031.08975 (for 35 hp) N and 7041.17 N (for 45 hp)

Torque=270600 N-mm (for 35 hp) and 315920 N-mm (see Appendix-I &II)

The Design analysis of rotavator components with an output file generated by simulation with respect to yield stress and deformation obtained by using field conditions[11] in the Post processor. The blade Vs Soil interface with field parameters and boundary conditions are simulated with following effects on blade see Appendix-I.



Deformation and stress plot for 35 hp tractor

Deformation and stress plot for 45 hp tractor

Figure 2 Deformation plots and stress distribution in rotavator assembly

3.1 Blade analysis

1) The maximum Displacement vector sum in: 6.757 mm (35 hp) and 7.893 mm (45 hp)

2) The maximum Von Mises Stress: 417.03 MPa (35 hp) and 503.20 MPa (45 hp)

3) The maximum principal stress for 35 hp tractor is 490 MPa and for 45 hp, 577 MPa was observed in the blade section which is less than the yield stress of blade material, i.e 690 MPa.

The Von Mises stresses and deformation plots on blade Vs Soil interface are as shown in the following.

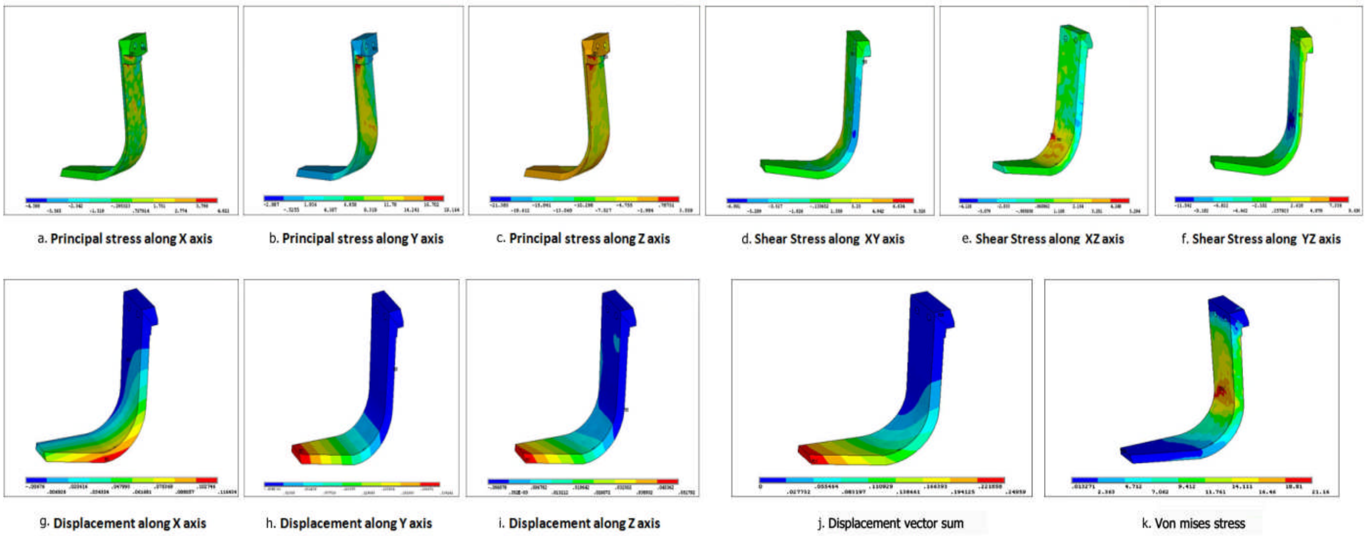


Figure 3 The principal stresses on blade component

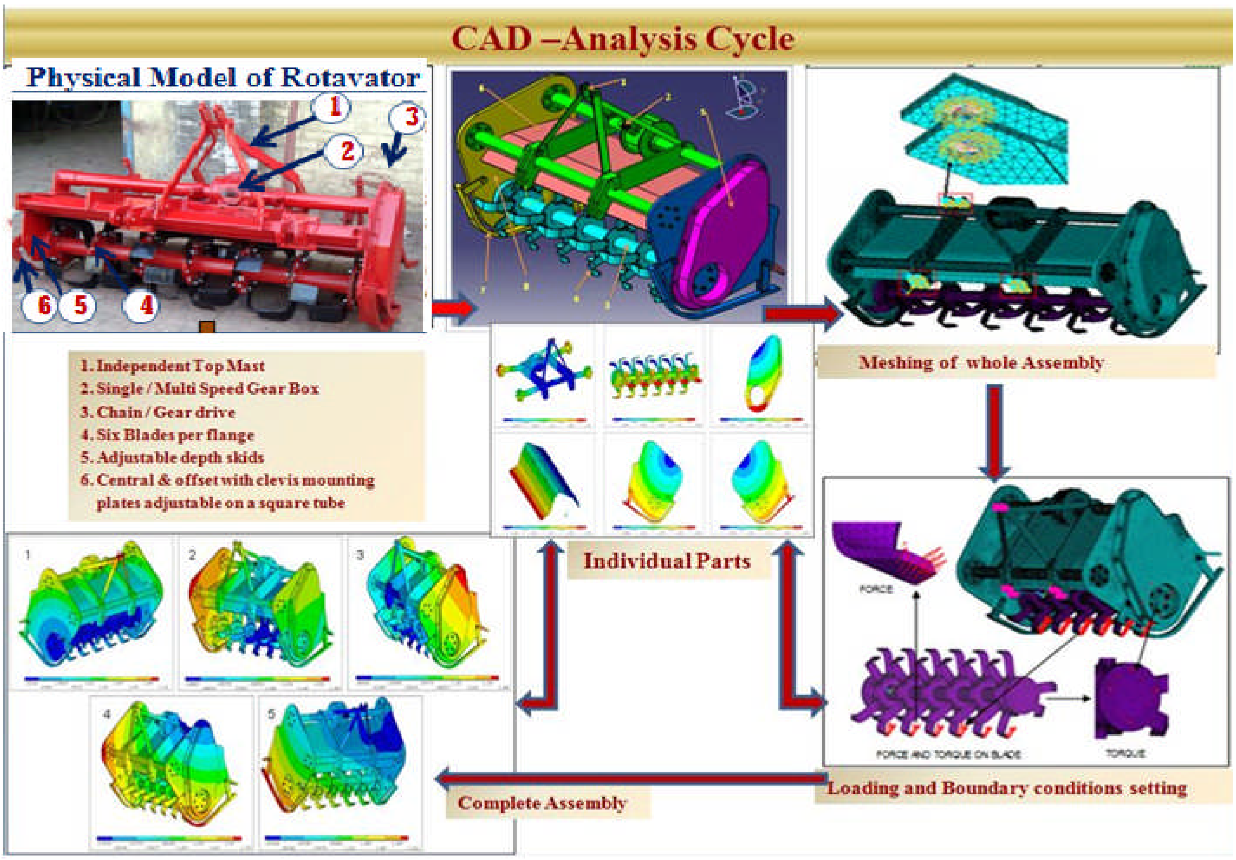


Figure 4 The CAD-analysis cycle

Appendix-I

1 Working Safety Coefficient for 35hp and 45hp tractors

Sr. No.	Component name	Yield stress/MPa	35 hp		45 hp	
			Von mises stress/MPa	Safety coeff.	Von mises stress/MPa	Safety coeff.
1	Independent Top Mast	500	404.297	1.24	471.465	1.06
2	Rotor with Blade	690	417.03	1.65	503.208	1.37
3	Side Gear Box Part	180	15.637	11.51	18.282	9.84
4	Frame and Cover	180	16.864	10.67	19.675	9.15
5	Left Side Frame	180	56.267	3.2	65.618	2.75
6	Right Side Frame	180	55.383	3.25	64.732	2.78

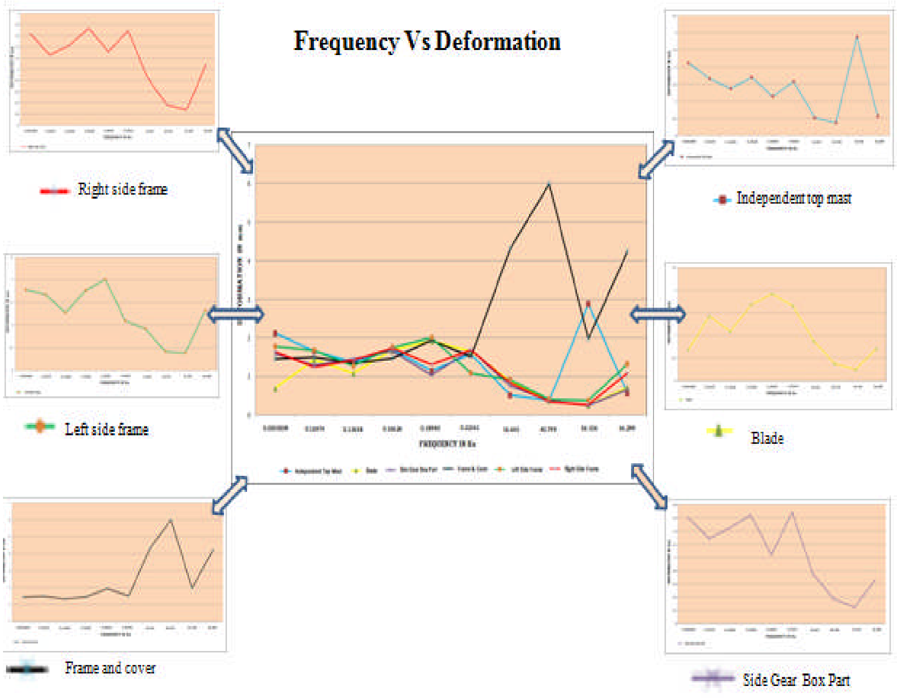
2 Stress of rotavator parts for 35 hp and 45 hp tractor

Sr. No.	Component name	35 hp tractor		45 hp tractor	
		Resultant displacement/mm	Von misses stress/MPa	Resultant displacement/mm	Von misses stress/MPa
1	Independent Top Mast	2.19	404.297	3.399	471.465
2	Rotor with Blade	6.757	417.03	7.893	503.208
3	Side Gear Box Part	5.658	15.637	6.612	18.282
4	Frame and Cover	6.526	16.864	7.893	19.675
5	Left Side Frame	6.583	56.267	7.683	65.618
6	Right Side Frame	6.684	55.383	7.609	64.732

Appendix-II

Frequency Vs Deformation plots for all six components as show below in Figure

Sr. No.	Frequency /Hz	Max deformation /mm	Remark (Rotavator componant)
1	3.51E-02	2.119	Top
2	0.12474	1.682	Front left
3	0.13638	1.449	Top Front
4	0.16626	1.767	Front left
5	0.1894	2.012	Bottom front
6	0.22161	1.693	Bottom Front
7	16.645	4.313	Front
8	40.799	5.994	Front Corner
9	56.556	2.883	Top Front
10	66.299	4.242	Bottom Front



Appendix-III

1 Material properties

Sr.No.	Material name	Material properties		
		Elastic modulus /N · mm^{-2}	Poission ratio	Density /Tonne · mm^{-2}
1	High Carbon steel	1.97 **x** e^{11}	0.29	7.48 **x** e^{-9}
2	Cast Iron	1.20 **x** e^{5}	0.28	7.20 **x** e^{-9}
3	Mild steel	2.10 **x** e^{5}	0.30	7.89 **x** e^{-9}

2 Soil resistance (kg/cm^2)

Sr. No.	Types of soil	Soil resistance /kg · cm^{-2}	Optimum moisture content/%
1	Sandy Soil	0.2	3.5
2	Sandy loam	0.3	3.5
3	Slit loam	0.35 - 0.5	5.8
4	Clay	0.40 – 0.56	7.18
5	Heavy loam	0.5 – 0.7	13.3

[References]

[1] Gill W R, Vanden Berg G E. Design of tillage tool. In soil dynamics in tillage and traction. 211–294. Washington, D.C., U. S. GPO. 1996.

[2] Salokhe V M, Ramalingam N. Effect of rotation direction of a rotary tiller on draft and power requirements in a Bangkok clay soil. Journal of Terramechanics, 2003; 39, 195–205.

[3] Ghosh B N. The power requirement of a rotary cultivator. J. Agric. Engg. Res., 1967; 12(1): 5–12.

[4] Salokhe V M. Effect of blade type on power requirement and paddling quality of rotavator in wet clay soil. J. Terramechanics, 1993; 30(5): 337–350.

[5] David Roylance. Finite Element Analysis Method. Department of Materials Science and Engineering. Massachusetts Institute of Technology Cambridge, MA 02139 February 28. 2001.

[6] Altair Engineering. Inc, Hypermesh Users Guide, 2003.

[7] Hendrick James G, Gill William R. Rotary Tiller Design parameters depth of tillage. Transactions of ASAE, 1971; 675–683.

[8] Gupta J P, Pandey K P. Performance of rotary tines blade under wetland condition. Agric. Mech. in Asia, Africa and Latin America, 1996; 27(1): 16–20.

[9] Mootaz Abo-Elnor, Hamilton R, Boyle J T. Simulation of soil–blade interaction for sandy soil using advanced 3D finite element analysis. Soil & Tillage Research, 2004; 75: 61–73.

[10] Ansys Inc, ANSYS 8.1 Documentation, Structural Analysis Guide, Swansos Analysis System, United state, 2004.

[11] Salokhe V M, Chuenpakaranant W, Niyampa T. Effect of enamel coating on the performance of a tractor drawn rotavator. Journal of Terramechanics, 1999; 36: 127–138.