Computer-aided engineering approach for small farm holdings in West Bengal state of India

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Abstract: Small and marginal farms are one of the immense challenges for farm mechanization in the West Bengal state of India. Since the majority of farms are marginal with land holding less than one hectare, the use of high capacity equipment is not feasible. The major constraints in the promotion of farm mechanization include the fragmented land holding, low investment capacity of the farmers, the requirement of equipment for each agro-climatic zone of West Bengal, and inadequate repair and maintenance facilities, etc. So, small agricultural machinery is gaining importance for research. The cultivator is a secondary tillage tool mostly used in Indian farms. A 5-tyne cultivator may be suitable for small farm lands. So, in this present work, a 5-tyne cultivator was designed with computer aided engineering (CAE) approach. Simultaneously, finite element method (FEM) analysis was carried out for different test cases based on soil conditions which are a representation of the various zones of West Bengal. The FEM analysis ensures the failure condition of the cultivator for various test cases. With the CAE approach Equivalent (von-Mises) stress, total deformation, and maximum principle stress for each test case were generated. In simulation results, total deformation, equivalent (von-Mises) stress, and maximum principle stress range in between stress results were ranges in between 1.405-1.446 mm, 99.59-102.49 MPa, and 97.25-100.08 MPa, respectively. These results were compared with the yield point stress of the material of tine and shovel of the cultivator, which were found to be within the permissible limit. Thus, CAE approach is showing a promising tool for promoting farm mechanization in the West Bengal state of India.

Keywords: cultivator, marginal farm, computer aided engineering, computer-aided design, agriculture, farm mechanization

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1 Introduction

Farm mechanization is one of the main focus areas during the 12th five-year plan (2012-2017) of Government of India towards achieving a target of 6% annual growth in food grains (Karmakar et al., 2016). Agriculture is a key segment of the Indian economy, and over 70% of the country population depends on it as their main basis of income. Farmers are adopting contemporary agricultural technologies to increase farm yield due to the increase in demand for food supply. However, farm mechanization in India has not proceeded as anticipated. The extent of farm mechanization is enormously varied throughout the different states of India. Unlike the state of Punjab and Haryana, the eastern part of India viz. West Bengal, Bihar and Orissa retain lower levels of mechanization in terms of a high capacity machineries like combine harvesters (Singh et al., 2004). However, both the central and state government have taken several measures through different schemes, such as 'Promotion and Strengthening of Agricultural Mechanization through Training', 'Testing and Demonstration and Post-harvest Technology and Management' during the 11th five year plan (2007-2012). Parallel to this, mechanization is also promoted through other programs like Rashtriya Krishi Vikas Yojana (RKVY), Macro Management of Agriculture (MMA), National Horticulture Mission (NHM) and National Food Security Mission (NFSM), etc. as documented by Ministry of Agriculture and Farmers Welfare, Government of India, 2016. The tailback in farm

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mechanization is affected by the non-availability of improved equipment, small and scattered land holding and low investing capacity of the farmers (Dixit et al., 2014). Farm mechanization scenario in West Bengal has been investigated by different researchers (Sarkar and Roy, 2014; Tewari et al., 2012) and suggestions have been made to improve small farming equipment.

According to the distribution of land holdings of the state (Table 1), about 82.16% is marginal farms (with less than 1 hectare of land size). Since the majority of farms are marginal (<1 ha), the use of high capacity implements is not suitable. So, most of the farmers are accepting the small machnery like power tillers at a fast pace in the state. Chauhan et al. (2006) reported that improvement of the efficiency of energy use can be done with the better use of power tillers and the introduction of improved machinery.

Table 1 Percentage distribution of a number of operational holdings for all social groups in West Bengal (2010-2011), Ministry of Agriculture, Govt. of India

State	Marginal	Small	Semi-Medium	Medium	Large
West Bengal	82.16	13.76	3.75	0.32	0.01
India	67.04	17.93	10.05	4.25	0.73

Cultivators are secondary tilling implements that mean, farmers use cultivators after land is initially ploughed to prepare a seedbed for the crop, entomb crop residue in the soil and control weeds (Tamás and Jóri, 2010). Though in the small field, one cannot go for mechanization with traditional tractor operated 9-tyne or large size cultivator. So, there is a need for a small implement to be designed. But, in practice, farmers face some problem like breakage of shovel tip because of the material of shovel, soil, root, stone, etc. Therefore, it is imperative for the agricultural engineers, designers and agricultural machinery manufacturers to predict deformation and structural stress distributions on the machine elements during tillage operations and at the same time it should take different materials and different soil conditions.

Computer-aided design (CAD) is becoming one of the most valuable software tools in the design and manufacturing industry. It uses the computer technology to assist in the design, modification, analysis and optimization of design. ANSYS provide all features desired to develop and analyse the stresses and forces without making the physical model. The ANSYS structural analysis software suite solves complex engineering structural problems and helps in making better and faster design decisions. Although much research can be found about finite element method (FEM) on agricultural implements, its effects or soil interaction conditions, limited studies have been done about the structural optimization of the construction and constituent elements using computer-aided engineering (CAE) applications for small machinery which are suitable for marginal farms. However, a few similar studies related to CAE approach on agricultural machineries have been presented in agricultural engineering research. Badegaonkar et al. (2010) conducted an experimental on the investigation of cultivator shank shape on the draft requirement. They used duck foot sweep cultivator type to measure draft and vertical force values at different bend angle, bend length and operational depths. Makange et al. (2015) and Raut et al. (2014) investigated the failure in the shovel due to different loading condition at a different speed in the medium black soil. Influence of tillage depth and forward velocity on the soil/tillage tool interaction force was investigated by Moenifar et al. (2014).

The present study aims with the main objective of designing a 5-tyne cultivator which is suitable for small land holding systems. Failure of tyne in different soil condition was also simulated with CAE approach. The design of experiment has been conducted to simulate the best field condition for the entire West Bengal, and then analysis has been carried out for the same. This paper is organized as follows: in Section 2, a description of the materials and methods are provided. This section includes CAD design model for 5-tyne cultivator, the design of experiment for simulations, and FEM analysis for different test cases. The results of the simulation analysis are presented in Section 3. We have concluded in Section 4 by showing the advantages of the proposed approach and the limitations therein.

2 Materials and methods

2.1 Prototype

Actual dimensions of the traditional cultivator are considered while preparing the CAD-solid model. A cultivator prototype was taken from Faculty of Agricultural Engineering, Bidhan Chandra Krishi Viswavidyalaya (Agricultural University), India. The technical specification is shown in Table 2. The prototype is shown in Figure 1, which has five tynes and suitable for small farming. The cultivator was developed based on ISO 5680:1979 (1979). This international standard deals with tynes and shovels for cultivator according to their method of attachment. This standard specifies only the main fixing dimensions. So, there is a need for future design and configuration. A 5-tyne cultivator is generally used as a secondary tillage equipment mostly on dry land for tillage, removal of crop roots and stubbles, weeds and for inter cultivation in orchards, etc.

The materials of cultivator are taken from the manufacturing database of cultivator production system according to following data in Table 3.

Table 2 Specification of 5-tyne cultivator prototype

Mainframe	Solid bar (50 mm × 10 mm)
Dimensions	Length (front - 685.8 mm, rear - 660.4 mm) × width 711.2 mm × height - 614.2 mm
Depth adjustable	Adjustable screw provided for depth adjustment
Shovel	Thickness - 6 mm, width - 60 mm
Shovel type	EN 8
Frame and tyne type	Mild steel
Row distance	Fixed - 152.4 mm

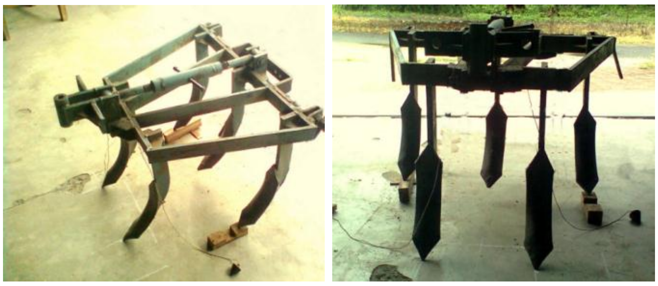


Figure 1 The 5-tyne cultivator prototype with isometric and front view

Table 3 Material properties of the cultivator (Automations Creations, Inc., 1997)

Material	Material properties (Normalized)					
	Standard	Elastic modulus, N mm^{-2}	Poisson ratio	Yield strength, MPa	Tensile strength, MPa	Elongation, %
EN8	BS 970	2.1×10^5	0.27-0.30	280	550	16
Mild steel	IS2062 Grade B	2.1×10^5	0.303	240	410	20

2.2 Design of CAD model

With the specification in Table 2, a working model was developed in CAD platform. Autodesk AutoCAD 2016 was used for preparing the model as shown in Figure 2.

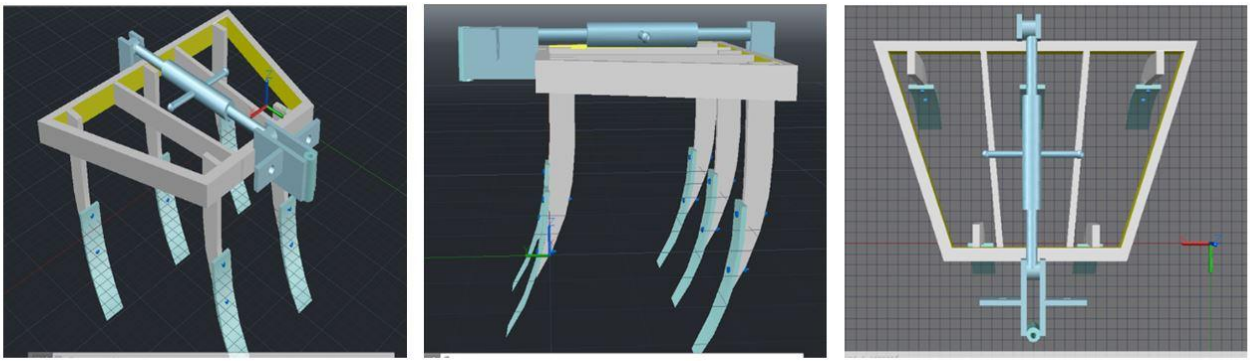


Figure 2 AutoCAD model of 5-tyne cultivator

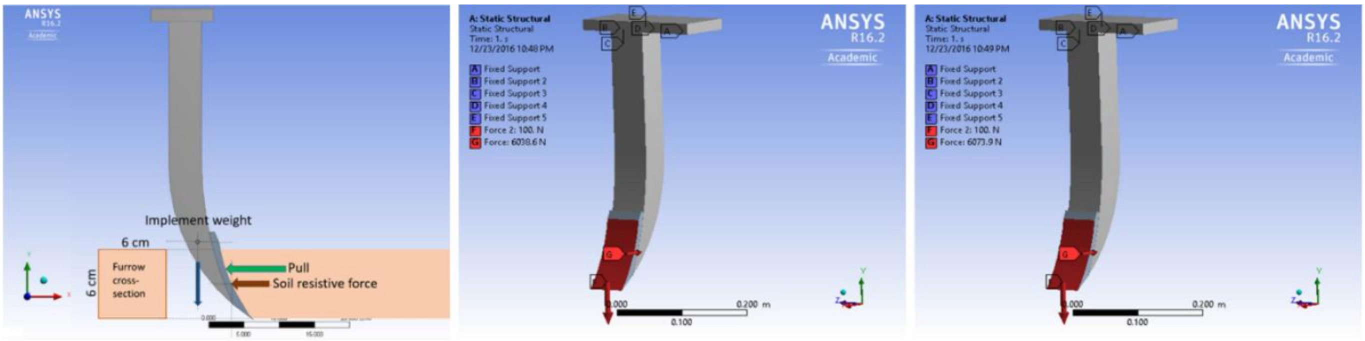
2.3 Design of experiment for simulation

The cultivator was specifically designed for the West Bengal state of India. Though West Bengal is mainly falling in new alluvial soil regions, it also consists of red and lateritic soils, red gravelly soil, and coastal alluvial soil zones (Haldar et al., 1992). Soil texture also varies throughout the zones. So, designing a cultivator for different soil type was conducted for the present work. As soil type changes, the draft on the cultivator also changes accordingly (Tagar et al., 2014). This is due to the difference in soil resistance in different soil type as shown in Table 4.

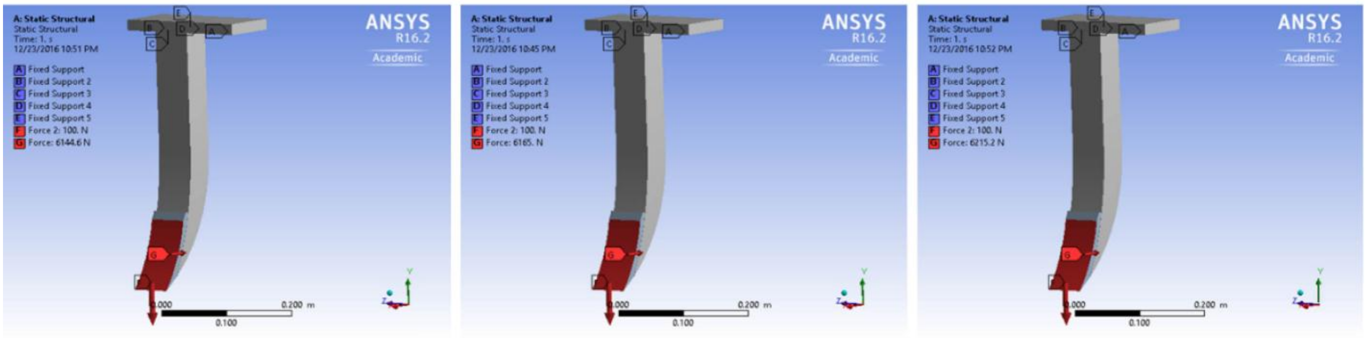
Table 4 Soil resistance in different soil type (Raut et al., 2014)

Type of soil	Soil resistance, kg cm^{-2}	Optimum soil moisture. %
Sandy soil	0.2	3.5
Sandy loam	0.3	5.8
Silt loam	0.35-0.5	5.8
Clay	0.4-0.56	7.18
Heavy loam	0.5-0.7	13.3

The simulation was carried out in five sets of the experimental setup. In each configuration, soil resistive force is varying according to Table 4. But, other parameters such as pulling force, implement self-load, and material combination remain constant. Thus, each experimental setup is representing simulations for the different soil type in different zones of West Bengal for the designed cultivator.



a. Force analysis on single tyne b. Experimental setup for simulation case- Sandy soil c. Experimental setup for simulation case-Sandy loam



d. Experimental setup for simulation case-Silt loam e. Experimental setup for simulation case-Clay f. Experimental setup for simulation case-Heavy loam

Figure 3 Experimental setup for different simulations cases.

In each experiment, the pulling force can be calculated for a 15 HP power tiller with 1.35 km h^{-1} operational speed. Power tillers are the principal power source for small farm holdings. Thus, the experiments can be suitable for small land agricultural practice.

Mandal (2016) illustrated the force interaction on rigid tyne cultivator. The power consumed for operation can be expressed as Equation (1):

$$Power = Force \times velocity \quad (1)$$

Or, Equation (2):

$$15 \text{ HP} \times 746 = Force \times 1.35 \text{ km h}^{-1} \quad (2)$$

So, *Force* = 29840 N for 5 tynes

Pulling force for each tyne = 29840/5 = 5968 N.

Now, cross sectional area of each shovel cut = 6 cm × 6 cm = 36 cm^2

Soil resistive force (in case of sandy soil) on each tyne = 0.2 kg cm^{-2} × 9.81 × 36 cm^2 = 70.63 N.

So, *total force* in the direction of motion = *Pulling force* + *Soil resistive force* = 5968+70.63 = 6038.63 N (Raut et al., 2014).

Following the same procedure, for other types of soil, total force was calculated. The vertical force on each tyne was calculated with (implement load/No. of tynes) and found to be 100 N. A share force and bending moment diagram is shown for sandy soil condition in Figure 4. The five simulation run is shown in Figure 3.

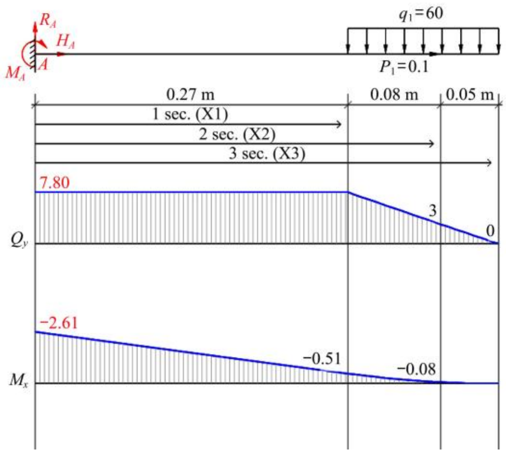


Figure 4 Shear force (Q_y) and bending moment (M_x) diagram of cultivator tyne considering, Cultivator tyne as a cantilever beam fixed at point *A*. Cultivator self-load, P_1=0.1 kN and soil resistive force (q_1) as a distributed load of 60 kN m^{-1} on tyne

2.4 FEM analysis

The design and analysis have been carried out with the help of 3D modeling software and FEA technique using ANSYS. In the boundary condition, cultivator was fixed at top, which means to the frame structure of the cultivator. The solution procedure using FEM includes various steps to be followed.

2.4.1 Geometry specification

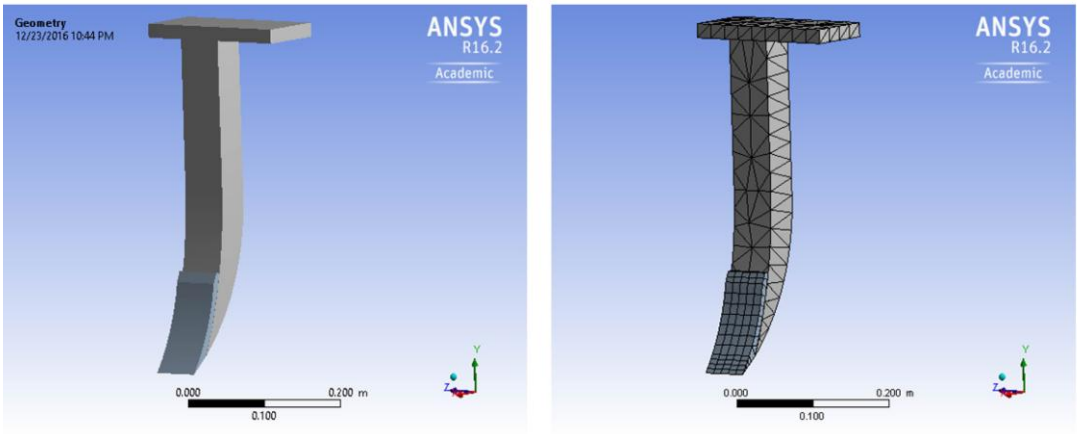
Firstly, the geometry of the assembly to be analyzed is defined. This can be arranged by importing the model from a solid modeler like AutoCAD Inventor Fusion, CATIA V6 or Pro/ENGINEER. For the cultivator modeling and cultivator, tyne modeling has been done by using AutoCAD software. First modeling has been done for all the parts and then assembled. Assembled file of cultivator was saved in IGES format (Figure 5a) and exported to the ANSYS Workbench environment.

2.4.2 Engineering material properties selection

The material properties are defined within the ANSYS Workbench, for all elements as specified. For any elastic system analysis, the material properties include Young’s modulus, yield stress, tensile strength, and the Poisson's ratio of the material. The mild steel (IS2062) was selected for frame and shank of cultivator and EN8 has been chosen for shovel according to Table 3.

2.4.3 Object meshing

The geometry structure is meshed into small elements. This is an important part of FEM analysis (Schneiders and Bünten, 1995). The meshing is completed with tri or quad method to inhabit the maximum geometric surfaces (Figure 5b) on the parts to create nodes for getting the optimum results of stresses.



a. Geometry of the object b. Meshing and finite element divisions

Figure 5 Cultivator tyne geometry

2.4.4 Boundary conditions and loading

It includes the boundary conditions (e.g. location of supports) and the external loads. For cultivator tyne, it was fixed at the top, where it is attached to the frame structure of the cultivator. The loading state such as the soil resistance which is acting as a resistive force against tyne and frame is defined.

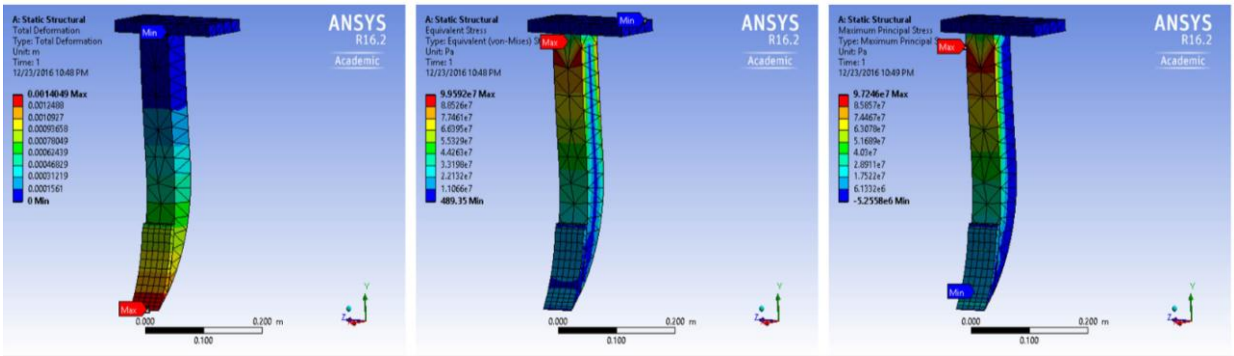
2.4.5 Processing or solution

The analysis is made on the previously input parameters. The modified algebraic equations are solved to find the nodal values of the primary variable. Equivalent (von-Mises) stress, total deformation, and maximum principle stress were selected for a solution. A similar method was applied for five test cases as mentioned in Figure 3. Then the stress results were compared with the yield point stress of tyne material.

3 Results and discussion

In this present work, CAD model has been developed as per specified dimension by using AutoCAD software followed by the FEM analysis using ANSYS software. Equivalent (von-Mises) stress, total deformation, and maximum principle stress were calculated and the following solution has been obtained in Figure 6 and Figure 7.

In all cases, maximum total deformation occurs in shovel tip, where more soil interaction happens with the tyne. Similar results have been reported by Makange et al. (2015) with 9 tyne cultivator having St 52 material tynes. The base part of the shank where it is fixed to the frame



a. Total deformation b. Equivalent (von Mises) stress c. Maximum principle stress

Figure 6 ANSYS simulation results for sandy soil case

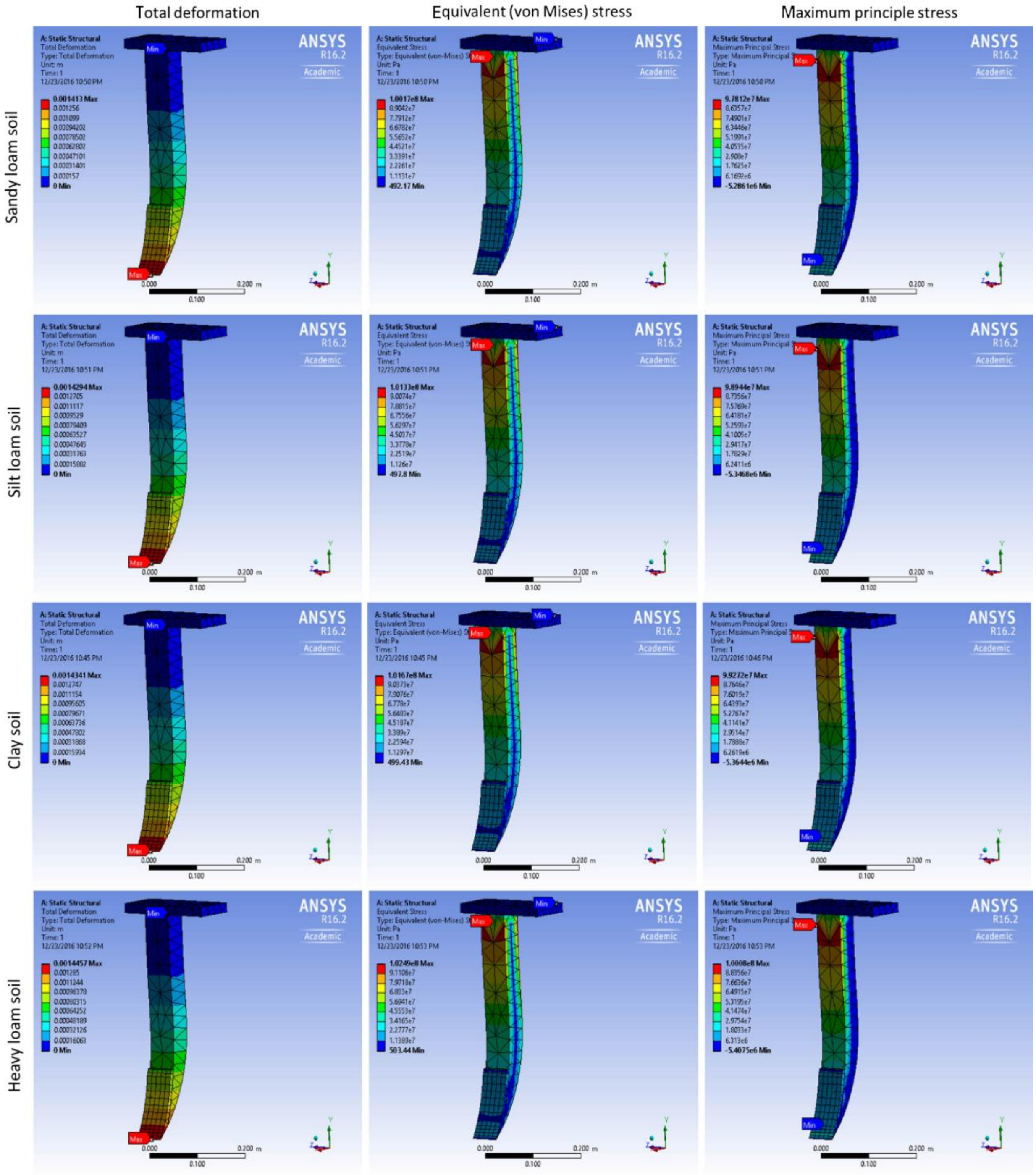


Figure 7 ANSYS simulation results of total deformation, equivalent (von Mises) stress, and maximum principle stress for sandy loam, silt loam, clay and heavy loam soil test cases. Each row represents results for each test case. Max and Min tags in each results showing maximum and minimum value of the output

were facing more equivalent (von-Mises) stress and maximum principle stress. Galat and Ingale (2016) investigated failure analysis of agricultural 9 tyne cultivator in different soil condition and found the similar response.

In sandy soil simulation case, total deformation is 0-1.405 mm. The maximum equivalent stress and maximum principle stresses are 99.59 and 97.25 MPa, respectively. In sandy loam soil case, total deformation ranges from 0 to 1.41 mm. The maximum equivalent stress and maximum principle stresses are 100.17 and 97.81 MPa, respectively. For clay soil, maximum total deformation is 1.43 mm. The maximum equivalent stress and maximum principle stress are increased to 101.67 and 99.27 MPa respectively. With respect to loose sandy soil, for compact heavy loamy soil, maximum equivalent stress and maximum principle stress are increased to 102.49 and 100.08 MPa, respectively.

The stress results of each test cases were compared with the yield point stress (240 and 280 MPa) of the tine's material (Table 3) and found that the maximum stresses did not exceed the yield point. It signifies that deformation does not cause failure on the tyne. Visual investigations of the tyne also confirmed that there was no significant deformation on the tyne.

There is an increasing trend in stress parameters as the soil is becoming compact and reduction in sand content from soil texture. A trend analysis of similar pattern has found from the ANSYS solution and represented in Figure 8.

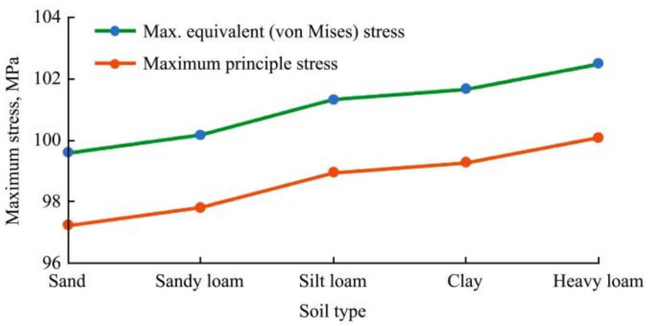


Figure 8 Maximum stress for different soil condition based on ANSYS simulation output

4 Conclusions

A CAD model for 5-tyne cultivator has been developed in this present work. Then the CAD model was tested for five different test cases which are a representation of different soil conditions of West Bengal state. Results calculated from the model support the following conclusions: (1) The CAE approach proved to be an appropriate tool in development and analysis of the performance of cultivator tynes for different soil conditions; (2) Different shear stresses equivalent (von-Mises) stress, total deformation, and maximum principle stress for each test case were generated. A comparison of these stress results with the yield point stress of the tyne's material produces promising results which are within permissible limit. The advantages of CAE approach over any traditional method for cultivator design are evaluation and refinement of design can be using computer simulations rather than physical prototype testing, thus cost economic and saving time. CAE approach can provide the performance of the designed model earlier in the development process when design changes are less expensive to make. Though, after ANSYS simulation results, field testing reports can give a better opinion on failure. But, still designing a small farm suitable equipment with a CAE approach has a great importance on farm mechanization in West Bengal state.

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References

Automations Creations, Inc. 1997. MatWeb: the online materials information resource. Available at: http://www.library.ualberta.ca/databases/databaseinfo/index.cfm?ID=2209. Accessed 25 December 2016.

Badegaonkar, U. R., G. Dixit, and K. K. Pathak. 2010. An experimental investigation of cultivator shank shape on draft requirement. *Archives of Applied Science Research*, 2(6): 246–255.

Chauhan, N. S., P. K. Mohapatra, and K. P. Pandey. 2006. Improving energy productivity in paddy production through benchmarking-an application of data envelopment analysis.

Energy Conversion and Management, 47(9-10): 1063–1085.

Dixit, J., S. Sharma, and M. Ali. 2014. Present status, potential and future needs for mechanization of agricultural operations in Jammu and Kashmir state of India. *Agricultural Engineering International: CIGR Journal*, 16(3): 87–96.

Galat, U. N., and A. N. Ingale. 2016. Failure investigation and analysis of agricultural 9 tyne cultivator used in various soil condition. *International Journal on Recent and Innovation trends in Computing and Communication*, 4(1): 173–179.

Haldar, A. K., C. J. Thampi, and J. Sehgal. 1992. *Soils of West Bengal for Optimising Land Use*. India: National Bureau of Soil Survey & Land Use Planning.

International Organization for Standardization. 1979. Equipment for working soil tines and shovels for cultivators-main fixing dimensions (ISO 5680: 1979). Retrieved from https://www.iso.org/standard/11792.html

Karmakar, S., S. Roy, P. Mandal, and R. Majumder. 2016. Evaluation of tractor drawn potato planter in West Bengal state of India. *Ama Agricultural Mechanization in Asia Africa and Latin America*, 2016, 47(3): 36–40.

Makange, N., R. Parmar, and V. Tiwari. 2015. Stress analysis on tyne of cultivator using finite element method. *Trends in Biosciences*, 8(15): 3919–3923.

Mandal, D. 2016. *Concepts of Farm Machinery and Power*. India: Narendra Publishing House.

Ministry of Agriculture and Farmers Welfare, Government of India. 2016. National portal on mechanization and technology. Available at: http://farmech.dac.gov.in/. Accessed 25 December 2016.

Moeinfar, A., S. R. Mousavi-Seyedi, and D. Kalantari. 2014. Influence of tillage depth, penetration angle and forward speed on the soil/thin-blade interaction force. *Agricultural Engineering International: CIGR Journal*, 16(1): 69–74.

Raut, M. P. M., G. V. Thakre, R. D. Thakre, and U. D. Gulhane. 2014. FEM analysis of nine tyne medium duty cultivator. *IORD Journal of Science & Technology*, 1(5): 58–65.

Sarkar, D., and D. Roy. 2014. Programmes and trends of farm mechanization in West Bengal, India. *International Journal of Advanced Research in Management and Social Sciences*, 3(1): 68–77.

Schneiders, R., and R. Bünten. 1995. Automatic generation of hexahedral finite element meshes. *Computer Aided Geometric Design*, 12(7): 693–707.

Singh, S., V. Bector, and A. Sharda. 2004. Role of farm mechanization in production agriculture in India. *Agricultural Engineering Today*, 28(3-4): 22–28.

Tagar, A. A., C. Ji, Q. Ding, J. Adamowski, F. A. Chandio, and I. A. Mari. 2014. Soil failure patterns and draft as influenced by consistency limits: An evaluation of the remolded soil cutting test. *Soil and Tillage Research*, 137(1): 58–66.

Tamás, K., and I. J. Jóri. 2010. DEM analysis of the soil-tool (sweep) interaction. In *Proc. 17th World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)*, 1-11. Quebec City, 13-17 June.

Tewari, V. K., A. A. Kumar, S. P. Kumar, and B. Nare. 2012. Farm mechanization status of West Bengal in India. *Basic Research Journal of Agricultural Science and Review*, 1(6): 139–146.