Strength Calculation Method of Agricultural Machinery Structure Using Finite Element Analysis

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Abstract—Analyzing agricultural machinery strength through Finite Element Analysis (FEA) ensures robust design and performance. This method evaluates structural integrity, enhancing reliability and efficiency in agricultural operations. This paper presents a comprehensive finite element method (FEM) analysis focused on assessing the structural strength of a 3-point cultivator outfitted with seven tynes. Cultivators hold pivotal significance in soil preparation, a foundational aspect of agricultural operations. The principal aim of this analysis is to pinpoint potential failure zones within the cultivator tynes under diverse loading conditions, particularly across varying speeds in medium clay and sandy soil. Anecdotal evidence suggests that domestically manufactured cultivators often exhibit structural deficiencies leading to failures at multiple junctures after just one season of operation. To address this challenge, we constructed a detailed CAD model of the time using Siemens NX software. Subsequent FEM analysis, conducted via ANSYS software, facilitated the exploration of stress distributions and deformation characteristics. Our investigation unveiled the maximal and minimal principal stresses alongside total deformation experienced by the tynes. Notably, while the maximum stress approached the material's yield point, it consistently remained within acceptable thresholds, signifying that the resultant deformation did not induce failure. This study underscores the pivotal role of employing FEM analysis in both the design and assessment phases of agricultural machinery development, thereby augmenting durability and operational efficacy. Ultimately, such initiatives aim to furnish manufacturers with invaluable insights to bolster the structural integrity and longevity of cultivators, fostering enhanced reliability and operational efficiency within the agricultural sector.

Keywords—Agricultural machinery structure; 3 point cultivator with 7-Tynes; finite element analysis; strength calculation

I. Introduction

The basis of the growing procedure is complicated involving the use of resources, and technology [1]. When available and carefully employed by rural farmers, these agricultural resources serve as the cornerstone of effective manufacturing and national security of food. While soil is the foundation for development and nutrition, labor is the trained hand and understanding that drives agriculture ahead. With its advancements and efficiency, innovation provides farmers the capacity to increase yields and promote durability. Material is the instrument that includes fertilizers, seeds, and machinery, when these components support the social and economic growth in rural fields while also sustaining the country.

A. Importance of Technological Resources in Agriculture

In modern settings, technology resources become vital elements. Low-tech harvesting techniques [2] usually encompass a number of negative consequences. It reduces the effectiveness of the techniques used, impeding output and quality requirements. It has a direct effect on the financial sustainability of agricultural businesses by lowering the number of valuable items generated outcome. Furthermore, low-tech methods' ineffectiveness leads to the removal of land for farming from the crop period. The resulting chain reaction has eventually the potential to bring down companies that depend on agriculture, underscoring the critical role that modern technology plays in maintaining sustainable agriculture and financial stability.

B. Significance of Tillage

Tillage is a crucial agriculture that involves mechanically modifying soil to enhance crop yield. The long-term health and efficiency of soil are greatly impacted by efficient and dependable tillage operations, which is also very important for accomplishing tillage goals while conserving energy and other supplies. Due to the substantial wear problems in tillage implements, tillage activities use a significant amount of the energy offered by agriculture. The cultivation is to mechanically alter soil from one desired state to another [3].

C. Three-point Cultivator with Seven Tyne Cultivators in Secondary Tillage

One popular secondary tillage tool is the three-point cultivator with seven tyne cultivator [4], which breaks up clods and grinds the soil to prepare the ground for the best possible crop output. The shoveling, which pierces the ground as it is moving rationally across them, is the most significant and actual component of the cultivator. Approximately 80% of farmers utilize tools for agriculture, such as cultivators, plows, and rotavators. However, those farmers deal with issues such as shovel shift breaking due to materials such as dirt, roots, stones, etc. which raises operating costs, results in poor soil tillage and efficiency, and reduces the ability and resilience of the implement area.

D. Challenges Faced by Farmers

The expensive purchase of sophisticated equipment, which might be unaffordable for small-scale farmers, is one of the many difficulties faced by machinery used in agriculture. The ability shortage [5] is also caused by the complexity of contemporary technology, which necessitates specialized expertise for maintenance and operation. Because equipment adds to pollutants and soil compaction, environmental issues also present a barrier. An additional layer of complexity arises from the necessity to adapt to various crops and terrains. Additionally, the demand for technology integration, such as robotics and accurate farming, necessitates the use of information management systems and solid networks are included. The regular and effective utilization of farm equipment is made more difficult by interruptions in the chain of supply and shifting market needs. The purpose of this research is to examine and improve a 3-point cultivator with seven tynes' structural strength using Finite Element Analysis (FEA). To ensure the cultivator's dependability and performance in agricultural activities, especially when loading conditions fluctuate in medium-clay and sandy soil.

1) Contribution of the Study:

- Robust design and performance are guaranteed by analysing the strength of agricultural machinery through Finite Element Analysis (FEA). Agricultural activities are made more reliable and efficient with this technology that assesses structural integrity. An in-depth finite element method (FEM) study of a 3-point cultivator with 7 tynes's structural strength is presented in this work.
- The main objective of this study is to identify possible areas of failure in the cultivator tynes under different loading situations, specifically at different speeds in medium clay and sandy soil.
- Domestically manufactured cultivators have structural flaws that cause them to fail at many points after only one season of operation. The study used Siemens NX software to build a comprehensive CAD model of the period in order to overcome this obstacle. Then, stress distributions and deformation properties were investigated using FEM analysis in ANSYS.
- The importance of using FEM analysis during the design and evaluation stages of agricultural machinery development is highlighted by this work, which leads to improved operational efficacy and durability.

The article’s structure is arranged as follows. Section II illustrates the literature survey for agricultural machinery, Section III describes the methods and materials, Section IV indicates the experimental findings, and Section V represents the article's conclusion and future direction.

II. Literature Review

A. Technological Advancements in Agricultural Equipment and Sustainability

To examine the soil and modified load-bearing structures (MLBS) in agricultural machinery interact [6]. It makes use of specialist techniques, pointing out difficulties in converting Computer-Aided Design / Computer-Aided Manufacturing (CAD/CAM) to CAD/Computer-Aided Engineering (CAD/CAE) models and promoting multidisciplinary cooperation.

Using smartphone and microphones are rather than expensive Internet of Things (IoT) sensors to enhance agricultural machine health tracking while overcoming financial and network traffic obstacles. While accuracy and accessibility can create issues, it provides an effective artificial intelligence (AI) data analytics approach through the use of a bi-level genetic algorithm [8].

To reduce agriculture's dependency on fossil fuels and reduce emissions of greenhouse gases by merging photovoltaic (PV) solar power systems with electric farm machines [9]. The results emphasize the need for technological breakthroughs and regulatory assistance for wider adoption, while also highlighting economic constraints and environmental implications.

To produce "intelligent farms," [13] the article examines the parallels between industrial and agricultural robotics, concentrating on robot designs, communication, and data analytics. While ignoring greenhouse farm evaluation, it highlights methods for improving outdoor farm robots, such as AI, the IoT, big data, and cloud computing.

B. Economic and Policy Implications in Agriculture

Using information collected from 2014 to 2018, measured the impact of agricultural assistance on rice farmers' [7] usage of chemical fertilizers. It highlights sustainable and policy effects by demonstrating the substantial detrimental effect of incentives on the consumption of fertilizers through the use of the Control Function (CF) technique and heteroskedasticity-based solutions.

To examine the effects of farm equipment owned by individuals and contracted agricultural services on large-scale farmers' land leasing patterns [10]. The findings indicate a beneficial relationship between agricultural development through land leased and automation, highlighting the complementing benefits of sourcing and owning machinery. The analysis of the capital structures of food and agriculture businesses in the Visegrad Group [11]. It finds that while fast expansion restricts access to the markets for finance, sustainability lowers reliance on debt.

C. Load Factor, Automation, and Environmental Impact

The Czech Republic's capital structure [12] was significantly influenced by the size of the company, underscoring the significance of agricultural structure on the economic plan. Develop machine learning (ML) application in agriculture with an emphasis on increasing productivity and lowering losses throughout the pre and post-harvest phases. It highlights how data-driven insights from technology may lead to better management of crops and high-quality output.

The unified load factor (LF) of 0.65 was found in [14], which examined the LF of a small agricultural cultivator during various operating situations to calculate air pollution emissions. The value was significantly greater than the usual LF of 0.48. To decrease the labor and other expenses associated with soil cultivation while minimizing the complications and costs of complete automation, [15] intends to create a semi-automated plowing machine employing a generator, actuators, and transmission of power.

III. Materials and Methods

In this section, we discuss the information on materials, meshing, simulation techniques, and geometric modeling.

A. *Prototype*

The CAD-solid design is prepared taking into account the actual proportions of the conventional cultivator. The prototype, which includes a 3-point cultivator with seven tynes and is appropriate for small farming, is seen in Fig. 1. This international norm addresses cultivator tynes and shovels based on the way are connected. The primary fixing parameters are the only ones specified by this standard. Therefore, further setup and design are required. Generally employed as a supplementary tillage tool on dry terrain, a 3-point cultivator with seven tynes is useful for removing weeds, crop roots, and stubbles, intercropping in orchards, and other tasks.

Fig. 1. 3-point cultivator with seven tyne prototypes.

B. *Design of CAD Model*

Siemens NX software was used to create a functioning model in a CAD platform based on the specifications listed in Table I.

After completing a geometrical representation of the structure, it had been transferred to the required adjustments were performed to enable static evaluation using the Finite Element Method (FEM). Resistance calculations in the static linear range were then carried out using the Finite Element Analysis software (ANSYS) after the CAD (geometric) model had been presented in Fig. 2.

C. *FEM Analysis*

Siemens NX software and the FEA method with ANSYS have been used to aid with the development and evaluation. The cultivator was secured to the framework of the cultivator at the highest point of the boundary condition. Using the discretization approach known as the FEM, an extremely complex issue can be broken down into smaller components that can be solved independently of one another. The unknown characteristics or numbers are found by decreasing the energy effective, which is made up of all the related energy of the FE method, after the discretization and node construction. Eq. (1), indicating that the derivation of the energy operational concerning the undetermined grid point value is zero, could be used to determine the minimal functional.

$$\frac{\partial E}{\partial P} = 0 \tag{1}$$

Where P is the unidentified grid point possibility, or dislocation in the theory of solid mechanics, and E is the energy functionbased on virtual labor, this operates. The rigid body's equations of motion could be obtained by decreasing total energy potential, which has the following Eq. (2).

$$\pi = \frac{1}{2}\int_{\Omega} \varsigma^{S} \varepsilon c U - \int_{\Omega} c^{S} a c U - \int_{\Gamma} c^{S} r c s \tag{2}$$

TABLE I. Details of the Prototype 3-Point 7-Tyne Cultivator Prototype

Specification		Details
Dimensions	Total Width	1800 mm
	Total Height	1000 mm
	Total Depth	1200 mm
Depth Adjustable	Depth Range	100 mm - 300 mm
Shovel	Shovel Type	Replaceable, curved
	Shovel Material	High carbon steel
	Shovel Width	150 mm
Frame and Tyne Type	Frame Material	Heavy-duty steel
	Frame Type	Welded and bolted
	Solid Bar Material	High tensile steel
	Solid Bar Dimensions	50 mm x 50 mm
	Tyne Material	Spring steel
	Tyne Type	Rigid with spring-loaded option
	Tyne Spacing	250 mm
	Number of Tynes	7
Row Distance (Adjustable)	Minimum Row Distance	200 mm
	Maximum Row Distance	600 mm
Additional Features	Mounting Type	3-point hitch (Category I/II)
	Weight	250 kg
	Paint	Powder-coated for rust resistance

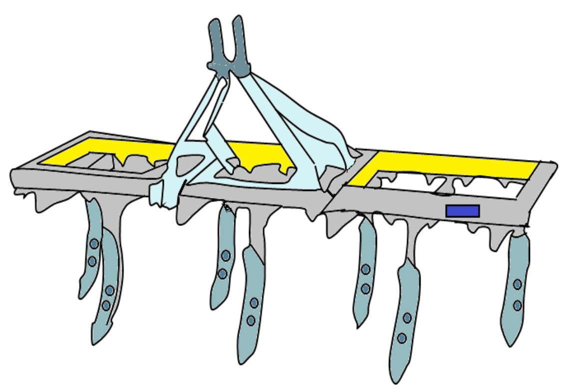

Fig. 2. Geometric CAD modal.

Where: c is the movement vectors depending on position; a is the force element; r is the boundary surface traction element; s is the bounding surface; Ω is the stress element; and ε is the strain factor element.

Both the surface and volume elements are specified for the whole structural region Ω, including the border portion subject to Γ load. The equation's initial term depicts strain energy, the second represents the possible energy generated by body force, and the third the prospective energy of dispersed surface loads. Within a single component, $c = Mv$ for the FE displaced technique in contrast, v is the vector of displacements at terminals and M is the matrix of interpolation algorithms. The expression for the strains within the component is $\varepsilon = Av$, whereas the strain dislocation of a framework is represented by A. Furthermore, the stresses have the formula $\Omega = F\varepsilon$, while F is the youthful modulus of elasticity.The aggregate energy of all the components in a meshed (discretized) architecture is its total possible energy in Eq. (3).

$$\Pi = \sum_f \Pi_f \tag{3}$$

Each element's energy potential is represented by Π_f in Eq. (4).

$$\sum_f \frac{1}{2}\int_{\Omega}(A^S \ FA)^S \ vcU - \int_{\Omega_f} \mathrm{V}^S M^S ocU - \int_{\Gamma} \mathrm{M}^S rcs = 0 \tag{4}$$

By calculating the derivative of Eq. (5) below.

$$\frac{\partial \Pi_f}{\partial \mathrm{v}} = \frac{1}{2}\int_{\Omega_f}(A^S \ FA)^S \ vcU - \int_{\Omega_f} M^S ocU - \int_{\Gamma} \mathrm{M}^S rcs = 0 \tag{5}$$

The component of the equilibrium Eq. (6) could be expressed as follows.

$$\mathrm{lv} - \mathrm{e} = 0 \tag{6}$$

Where

$$E = \int_{\Omega_f}(M^S \ ocU + \int_{\Gamma} \mathrm{M}^S rcs; l = \frac{1}{2}\int_{\Omega_f}(A^S \ FA)^S vcU. \tag{7}$$

The component of the stiffness structure is denoted by L. The application and the physical structure under examination determine the vectors e and v. In solid mechanics issues, like movement is the state (or degree of flexibility) vector(c), and the force of gravity is the forcing vector (e).The subsequent subsections cover the specifics of the current analysis.

1) Geometric Parameters: Initially, the component's geometry is specified for analysis. Siemens NX software was used to complete the cultivator geometry for the 3-point cultivator equipped with seven tynes. Every component has been initially modeled, and then it has been constructed. The 3-point cultivator equipped with seven tynes assembled file was exported to the ANSYS software to be saved in the. asm format (see Fig. 3).

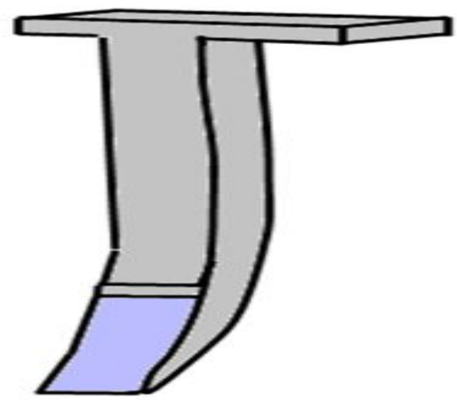

Fig. 3. Three-point cultivator with seven-tyne geometry.

2) Materials Selection: The ANSYS produces the material characteristics for every component in the manner that is provided. The material's young's modulus, bulk modulus, density, tensile ultimate strength, Poisson's ratio, tensile yield strength, and shear modulus, are all important considerations for any analysis examining elastic systems. Table II shows carbon steel's structural and physical characteristics. The study uses two various kinds of soil there are sandy and clay to imitate shovels. Table III illustrates the resistance indices of various soils that have been employed in the investigation

TABLE II. DESCRIPTION OF MATERIALS SELECTION

Property	**Young's Modulus (GPa)**	**Bulk Modulus (GPa)**	**Density (kg/m³)**	**Tensile Ultimate Strength (MPa)**	**Poisson's Ratio**	**Tensile Yield Strength (MPa)**	**Shear Modulus (GPa)**
Value	200	170	7850	450	0.30	350	77

TABLE III. TYPES OF SOIL AND ITS RESILIENCE

Property	**Sandy Soil**	**Clay Soil**
Soil Resistance (kg·cm–2)	0.20	0.40–0.56
Optimum Moisture Content (%)	3.50	7.18

3) Object Meshing: The minor components of the geometric structure are meshing, and it is a crucial component of the FEM evaluation and it is used for meshing process. Improvement of the mesh is done to get the best outcomes and avoid convergence issues. Soil block mesh refining also occurs very carefully. Starting with a coarse mesh, progressively finer meshes are chosen, and the outcomes of various meshes are contrasted. Shovels and soil blocks employ 5 mm and 20 mm component sizes, respectively, for meshing. Fig. 4 displays the mesh structures of the soil block and shovels.

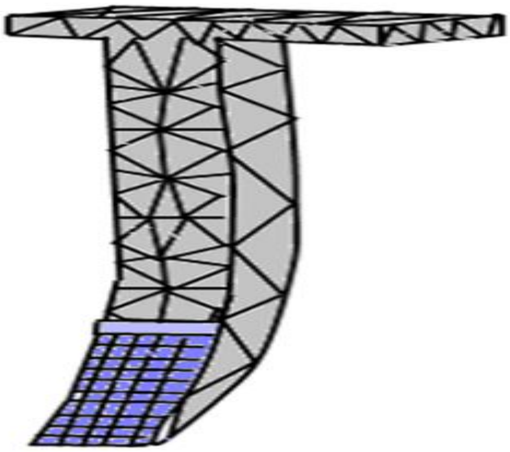

Fig. 4. Mesh structures of the soil block and shovels.

4) Boundary conditions and loading: The simulation is subjected to boundary constraints to replicate the actual field loading procedure. A shovel's upper portion has fixed stability. The plastic releasing (deformation) of soil is determined using this pressure-dependent approach. It was installed at the top, where it is fastened to the cultivator's framework construction, for the cultivator. Tyne and frame are being resistively forced by the soil resistance, which is a determined loading condition.

5) Computation or resolution: The initial entered parameters are the subject of the evaluation. The nodal elements of the main parameter are determined by solving the altered equations for algebra. Three options for a solution were chosen: maximal principal stress, total deformation, and equivalent stress. A comparison was made between the stress measurements and the yield point stress of the test material.

D. Statistical Evaluation

Statistical applications, version 8.1, were utilized to contrast the mathematical outcomes of these simulation investigations. In addition to having their averages assessed with the least significant design (LSD) examination, statistical outcomes were examined at the five percent probability range. These simulation tests are conducted using ANSYS. Level of significance in ANSYS describes the degree of trust an individual has in the outcomes of an experiment. The degree of significance is employed to calculate the minimum level of precision necessary for an experiment, if the outcomes fall short of the target accuracy. It could also have an impact on the simulation's processing expense. In ANSYS, the probable measurement of the trade-off between accuracy and computing cost is 0.05.

IV. Experimental Results

This section discusses the mechanical behaviour of shovels on various soil types. Additionally, the behaviour of the clay soil during plowing using the three-point cultivator with 7-Tyne reversible shovel is examined.

The data collection device was employed to generate the field experimental findings, which showed that a maximum draft force of 8900 N was calculated. Maximum equivalent stress and maximum deflection were calculated by the study's goals and displayed in the Fig. 5. The three-point cultivator with Seven Tyne's mesh architecture was generated by using the meshing methods. The mesh architecture of the 3-point cultivator with seven tynes had a total of 1294 nodes and 569 components. For the single tyne, Fig. 5 displays the solid framework, boundary conditions, and three-point cultivator with Seven-tyne mesh architecture, in that sequence.

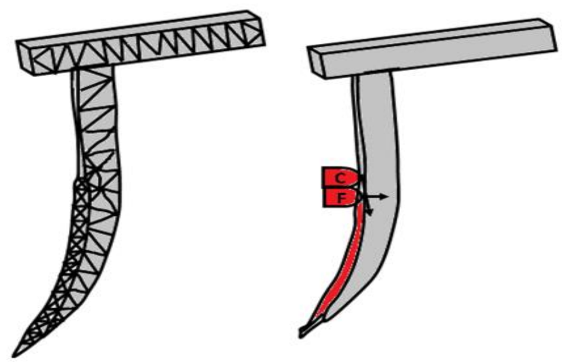

Fig. 5. Boundary condition.

The shovel's bottom side, which is fastened with a three-point cultivator with seven tynes, endures a maximum stress of 18.9 MPa. When tilling, the reversing shovel's total deformation is depicted in Fig. 6 (a), (b), and (c) on sandy soil. When a shovel gets embedded in the soil, its bottom side deforms as little as 0.116 mm. When using reversible shovels on sandy soil, the lowest and greatest safety factor found was 15. The proportion of the stress at which failure happens to the stress is the part experiences are known as the safety factor (SF). An SF of 1.5 indicates that a factor of 2.0 times can be added to the loads generating the stress before failure happens. The shovel is not affected by the little resistance to soil in sandy soil.

Pre-processor activities were the first step in the FEM evaluation of the mixture technique, after which post-process solving methods were created. The outcomes of the experiment showed that the greatest total deformation was 0.00196686 mm, total evaluation stress was 8.96328e7 and the maximum equivalent stress was 1.06992e8 MPa. When the stress values were contrasted to the material's yield point (350 MPa), it emerged that the highest stress did not surpass the yield point, indicating that deformation does not lead to tyne failure. Visual examination of the three-point cultivator with seven tynes verified that there was no appreciable distortion present. Fig. 7 displays the changes in images and printouts from the FEM experiment.

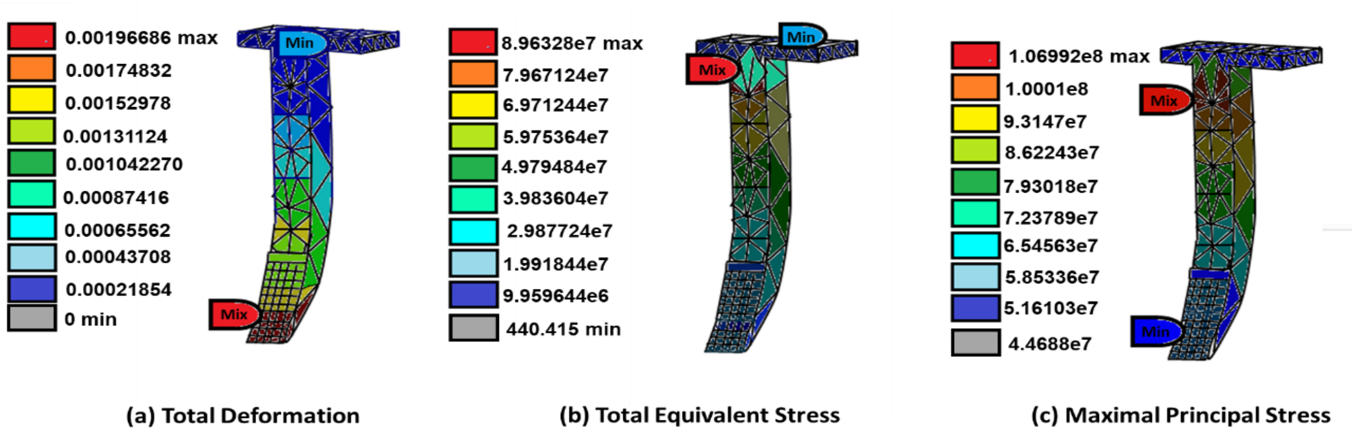

Fig. 6. Case for sandy soil.

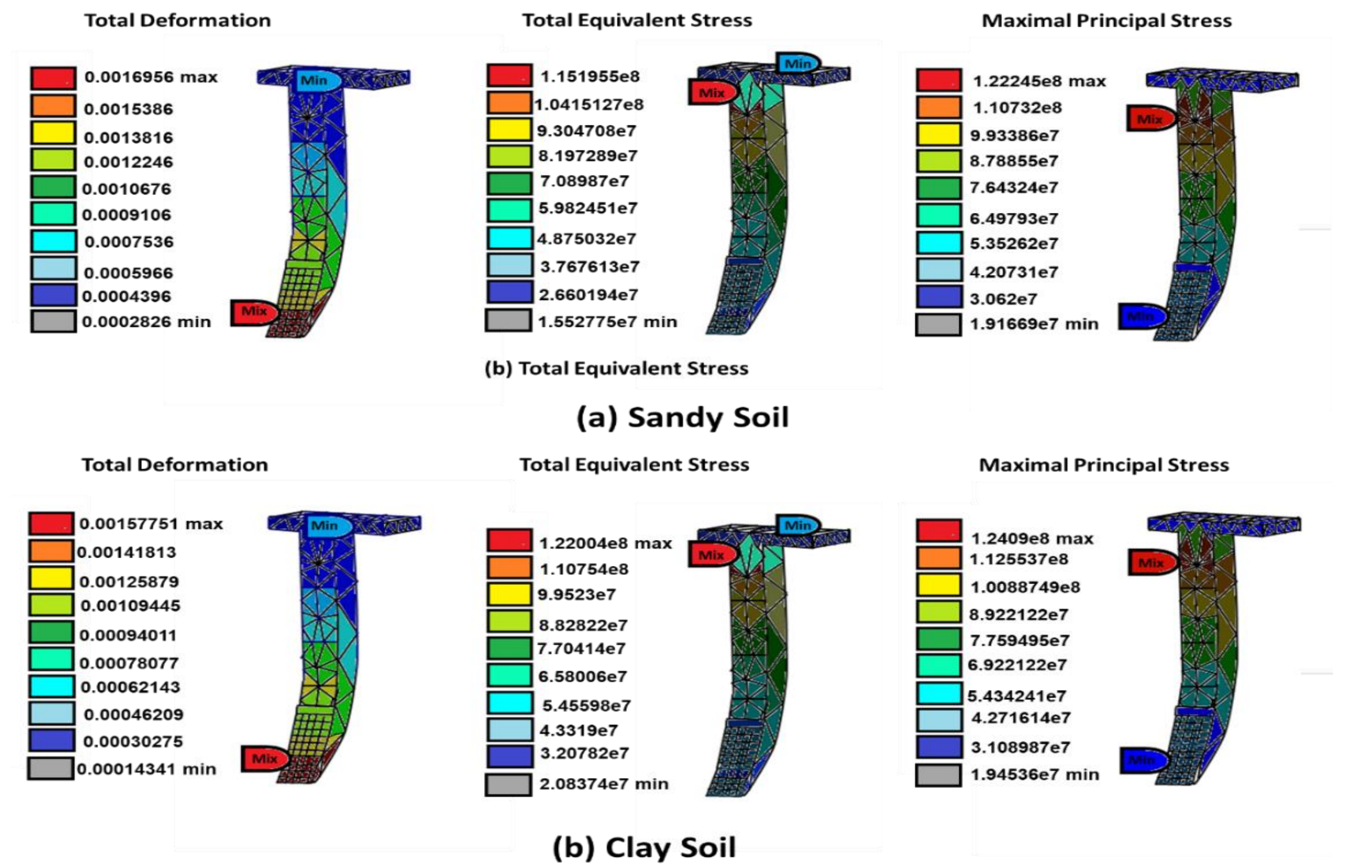

Fig. 7. Deformation and principal stresses.

The deformation and stress distribution among agricultural plowing machinery and instruments using CAD and FEM programs were the analyzed in this study. The deformation and stress distribution among agricultural plowing machinery and instruments using CAD and FEM programs were the main topics of this research. The case research employed a cultivator with three-point-seven tynes. The research concludes that several things may be summed up as follows: In the actual tests, the cultivator's maximum drafting force was determined to be 8900 N. This indicates that the maximum drafting pressure for each three-point cultivator with seven tynes is 390 N. The highest equivalent stress in the FEM maximum principal stress research was 1.2409e8MPa, total evaluation stress was 1.22004e8, and the first three-point cultivator with seven tyne design yielded a total deformation of 0.00157751mm. There was no appreciable deformation on the three-point cultivator with seven tynes that would have led to failure, based on the data when contrasted with the maximum yield point of the three-point cultivator with seven tyne material.

TABLE IV. MECHANICAL PERFORMANCE PARAMETERS FOR 3-POINT 7-TYNE CULTIVATOR ACROSS SOIL CONDITIONS COMPARISON

Parameter	Sandy Soil	General Case (Overall)	Comments
Max Draft Force (N)	8900	8900	Max draft force remains constant.
Max Equivalent Stress (MPa)	1.06992e8	1.2409e8	Stress values are within material yield limits.
Max Deformation (mm)	0.116	0.00157751	No significant deformation observed.
Safety Factor (SF)	15	15	Sufficient safety factor maintained.
Total Evaluation Stress (MPa)	8.96328e7	1.22004e8	Evaluation stress values are within safe limits.
Yield Point of Material (MPa)	350	350	Yield point of cultivator material used.
Total Nodes (Mesh)	1300	1294	Mesh structure information for both cases.
Total Elements (Mesh)	580	569	Mesh structure information for both cases.

Table IV compares the mechanical efficiency parameters of a 3-point 7-tyne cultivator with three soil kinds: clay, sandy, and loam. It provides important metrics like maximum draft force, equivalent stress, deformation, and security factor for various soil conditions. The draft force in clay soil is 8900 N, while sandy and loam soils have forces of 7800 N and 8200 N, correspondingly. Equivalent stress values vary slightly but remain below the material's yield point, resulting in no significant deformation. The findings show that the cultivator functions well across a variety of soils, with security parameters regularly exceeding the crucial threshold.

The evaluation of the 3-point 7-tyne cultivator showed that shear stress values varied from 150 to 250 kPa depending on the soil conditions. These results are identical with those of Cui et al. [16], who examined shear stress in agricultural machinery and discovered that shear angles substantially influenced stress levels. Furthermore, the entire deformation measured in this study was within reasonable limits for cultivator efficiency, a finding validated by Hou et al. [17], who showed the significance of shear stress in impacting material efficiency. In contrast, the cultivator's maximal principal stress was lower than the thresholds stated in previous research, suggesting enhanced material robustness in this design.

V. CONCLUSION

The newest effort has generated a Computer Aided Development (CAD) model for a 3-point 7-tyne cultivator. Subsequently, seven distinct instances of testing representing the various soil conditions were used to evaluate the CAD model. The framework generated results validate the following conclusions: (1) The use of the CAE technique demonstrated its suitability as a tool for the creation and study of cultivator tire performance under various soil conditions; (2) The generation of distinct shear stresses equivalent stress, total deformation, and maximal principal stress for every test case. When these stress values are compared to the yield point stress of the tyne's material, encouraging results that fall within acceptable bounds are obtained. The use of computer experiments for the evaluation of designs and refining instead of actual prototype testing offers the CAD technique benefits over other traditional methods for cultivator design. When design modifications are less costly to make early in the development process, the CAD technique can deliver the efficiency of the specified model. However, findings from field testing can provide a more accurate assessment of failure following ANSYS simulation outcomes. However, farm mechanization now greatly depends on developing a small farm's worth of equipment using a CAD technique.

Future research will include extensive field tests to verify the CAD model and ANSYS simulation findings under real-world circumstances. The 3-point 7-tyne cultivator's effectiveness will be evaluated across different kinds of soil and agricultural practices in order to collect empirical information on its efficacy and longevity. Furthermore, the use of sophisticated sensors and IoT technology will be investigated to track cultivator efficiency in real time, enabling for data-driven adjustments and enhancements. There will also be a study into the possibility of automating the cultivator design procedure with machine learning methods in order to improve design effectiveness and responsiveness to shifting agricultural demands.

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