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MODELING AND STATIC ANALYSIS OF A MOLDBOARD PLOUGH BY USING CAE TECHNIQUES

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Abstract: This paper presents the modeling and static analysis of a moldboard plough utilizing Computer-Aided Engineering (CAE) techniques. The study aims to enhance the design and performance of agricultural ploughs by leveraging advanced simulation tools. A detailed three-dimensional model of the moldboard plough is developed using Design software, capturing the geometric and material properties essential for accurate analysis. Static structural analysis is conducted using Finite Element Analysis (FEA) to evaluate the stress distribution, deformation, and potential failure points under typical operational loads. The results provide insights into the structural integrity and performance of the plough, identifying areas for design improvement to increase durability and efficiency. This research demonstrates the effectiveness of CAE in optimizing agricultural equipment, offering a robust framework for future development and innovation in agricultural machinery design

***Index Terms* -** Pro/ENGINEER, ANSYS for harmonic analysis, free mesh method, CK45 and ST52 Material

I. INTRODUCTION

For a very long time, agriculture has been and will continue to be the foundation of the Indian economy. A man who goes three days without meals will struggle, argue, and eventually perish after a week or so. One subfield of applied science is agriculture. The science and practice of farming, which includes tilling the soil, growing crops, and rearing livestock, is known as agriculture. It is the world's most significant business. Small-holder farmers have been cultivating between 2 and 3 hectares utilizing human labor and traditional instruments like a wooden plough, yoke, leveler, harrow, mallot, spade, huge sikle, etc. over the years. These implements are used for clearing weeds, planting seeds, and harvesting. The adoption and application of technology among small and marginal farmers differs greatly. The implementation of enhanced farming systems that conserve resources is crucial for the long-term enhancement of the standard of living of impoverished farmers in developing nations. Even if the majority of the required parts are already in place, there is a dearth of information regarding the functionality and availability of equipment, and there is ineffective communication between the department of agricultural research and development and farmers. The art and fundamental science of producing and enhancing field crops through the effective use of labor, water, soil fertility, and other crop-related resources is known as agriculture. It is the world's most significant business. Approximately 70% of Indians are farmers or work in some other agriculturally related capacity.

II. LITERATURE REVIEW

The various works are carried out in stress analysis, Modal analysis of automobile chassis brackets. Among which few are
categorized and discussed below

V.Madhava, et.al. The study investigated the impact of chisel plough configurations on various soil parameters, such as bulk density, water content, porosity, and weed control, using randomized block designs and statistical analysis to determine optimal shank positions for improved agricultural outcomes, including weed management [1]

Iryna Novakovska. et,al. The study comprehensively examines the mechanical and technological impacts of ploughing on soil fertility, considering factors such as crumbling frequency and structural strength restoration in the arable horizon under contemporary agricultural practices. It advocates for a judicious approach to employing mouldboard ploughs based on the soil structure coefficient of the upper layer (8-10 cm), intervening when it falls below 0.67. Additionally, it justifies the use of mouldboard ploughs with coulters or double-depth ploughs are optimizing the aggregation of ploughing machine-and-tractor setups, aiming to reduce energy costs associated with ploughing through efficient resource utilization.[2]

James Thompson . et.al. The research aimed to evaluate DSMP performance against two SMP models in a soil bin, testing a half-scale DSMP with 10% moisture content. Tillage quality and specific draft were measured at various speeds. Results were compared with prior experiments using similar SMP models with 14% moisture content. Findings suggest DSMP can serve as an effective alternative to SMP and RMP in field conditions with proper frame design.[3]

Hamed Shahmirzaei Jeshvaghani. Et.al. The evaluation criteria for ploughs, based on geometric parameters, include material quality, ease of manufacturing the moldboard, and quality of work execution. However, integrating these qualities is challenging due to the complex design process, particularly regarding the moldboard. Moldboards, being the primary working component of the plow, significantly influence its construction. For instance, while reversible ploughs offer higher efficiency and quality of work, the presence of two sets of moldboards increases cost, material quantity, and traction load, posing disadvantages. Moldboards with cylindrical working surfaces are common in agricultural engineering due to their favorable crumbling and turning factors, but they suffer from low ease of manufacturing due to non-developable surfaces.[4]

John Ndisya Mulwa. Et.al. The study investigated the impact of three independent variables tillage speed, tillage depth, and frog angle - on draught forces using both analytical methods (Saunders Equation) and numerical simulation (Discrete Element Method). Results highlighted that tillage depth exerts a stronger influence on draught forces than tillage speed, with minimal forces achieved at shallow depths and a frog angle of 30°. The study demonstrated the effectiveness of DEM in predicting draft forces accurately and optimizing tillage power, as well as determining the optimal frog angle for mouldboard ploughs.[5]

III. Objective of the Work

The objectives of the research for the structural analysis of a mounted moldboard plow using the finite element simulation method may include:

1. **PERFORMANCE EVALUATION**: Assessing the structural performance of the moldboard plow under various operating conditions, including different soil types, depths, and speeds.
2. **FAILURE ANALYSIS:** Identifying potential failure modes and weak points in the plow design to improve durability and reliability.
3. **OPTIMIZATION OF DESIGN**: Iteratively refining the design of the moldboard plow to enhance its structural integrity while minimizing weight and material usage.
4. **STRESS DISTRIBUTION ANALYSIS:** Analyzing the distribution of stresses and strains within the plow structure to ensure that it can withstand the anticipated loads without experiencing excessive deformation or failure.
5. **VALIDATION OF DESIGN STANDARDS:** Verifying that the design of the moldboard plow complies with relevant industry standards and regulations for structural integrity and safety.

IV. METHODOLOGY, PROBLEM IDENTIFICATION AND DESIGN PROPERTIES

A. Steps Involved In Methodology

Analyzing the structural behavior of a mounted moldboard plow using finite element simulation involves several steps. Here's a general methodology

The model is imported to ANSYS for harmonic analysis

- The chassis model is combined with all cross bar using VOLUME ADD.
- MESH the model by using free mesh method.
- Change the analysis type to harmonic from static conditions.
- Giving the minimum and maximum frequency values under the subsets of 100.
- Load conditions are given to chassis model and solve the problem.
- The model is tested for amplitude between Ck45 and ST52.
- Comparative study on performance and weight of the plough Ck45 and ST52 is to be done.

B. Problem identification

The plough serves multiple purposes, including the overturning of grass fields and incorporating crop residues and solid fertilizers into the soil. This process establishes an optimal seedbed, crucial for subsequent mechanical weed control measures. Without turning the soil, crop residues persist, posing challenges during harrowing. Furthermore, non-inversion tillage encourages the growth of grass weeds, which are notoriously difficult to manage mechanically in extensively planted crops.

Organic farmers may find themselves trapped in a detrimental cycle where non-inversion tillage exacerbates grass weed growth, hindering crop establishment and reducing competitiveness against weeds. In contrast, ploughing has a cleansing effect, dispersing weed seeds across a larger volume of soil compared to non-inversion tillage methods.

Perennial weeds, such as couch grass, thistles, perennial sow thistle, and coltsfoot, pose significant challenges for organic farmers. Ploughing plays a vital role in their control by disrupting the underground roots of thistles and perennial sow thistle, as well as the runners of couch grass and coltsfoot. Crucially, ploughing also buries these roots and runners at depths where they struggle to re-establish themselves, aiding in weed suppression.

C. MATERIAL Properties

The study simulates the three-bottom reversible mounted moldboard plow with its main parts labeled accordingly in Table 1 provides technical specifications, dimensions, and sizes for various components of the plow.

Table 1. Characteristics of the moldboard plow frame materials used in the FEM model.

Material	Density (kg m^{-3})	Elastic modulus (MPa)	Poisson's ratio	Yield stress (MPa)
CK45	7830	2.06×10^5	0.3	**414**
ST52	**7850**	**2.1×10^5**	**0.3**	**360**

- **MATERIAL ST52:** The St 52 Steel Plate, boasting a superior chemical composition including carbon, silicon, manganese, phosphorous, and sulfur, offers enhanced resistance to corrosive and oxidative media. With its low manganese carbon grade, the St52-3 Plate exerts minimal pressure on subsequent modules and is easily weldable using standard procedures. While slightly lower in strength and tolerance compared to the St52 plate, these versatile components meet various national and international standards. The St52 Steel Sheet, produced in thicknesses below 6mm and above 0.5mm, adds an aesthetic appeal to different components while not compromising stability.
- **MATERIAL CK45:** CK45 steel, characterized by its average carbon content of 0.45%, falls under the category of medium carbon steel and is recognized as one of the most commonly utilized non-alloy carbon steels in accordance with German standards. It is a medium carbon steel known for its balanced combination of strength, toughness, and wear resistance. Its moderate carbon content of around 0.45% provides good hardenability and strength without compromising on machinability. CK45 is often used in applications requiring components with high mechanical properties and resistance to wear and impact. Furthermore, its

moderate corrosion resistance and weldability make it a versatile choice for various industrial applications such as shafts, gears, bolts, and hydraulic cylinders.

D. DESIGN OF A PLOUGH

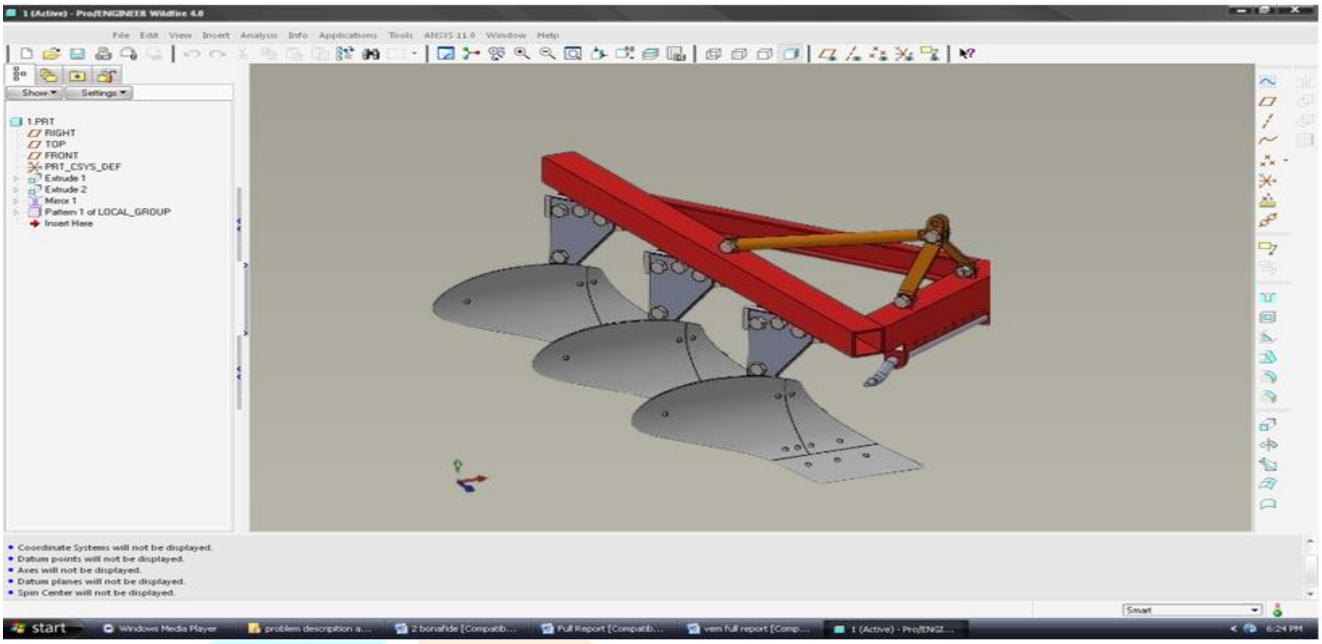


Figure 01 Design of a Plough by using Solid works

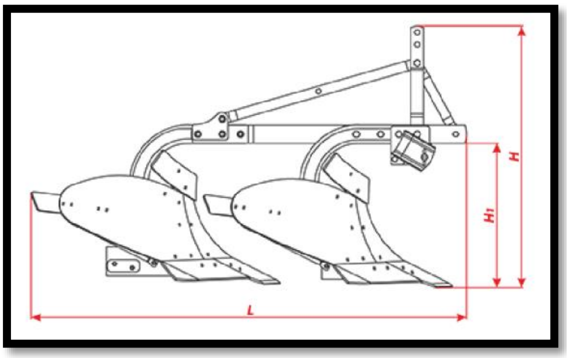
This image shows a 3D model of a multi-blade plow designed using CAD software (PTC Creo). The plow consists of a sturdy frame, multiple blades for cutting through soil, and a connecting mechanism for attachment to a tractor.

Study Explanation:

1. Objective: Analyze the mechanical performance of the plow under different operating conditions (varying depths and speeds) to ensure durability and efficiency.
2. CAD Modeling: Create and assemble the 3D model of the plow to visualize and simulate its operation.
3. Finite Element Analysis (FEA): Simulate the plow's behavior under real-world forces (lateral, vertical, draft) derived from previous data to evaluate stress, strain, and displacement.
4. Design Validation: Compare simulation results with material limits to identify potential issues and ensure the design can withstand the applied loads.
5. Optimization: Iteratively adjust the design based on simulation results to improve performance and durability.

Conclusion:

Using CAD and FEA, engineers can design a robust plow that meets operational demands, enhancing agricultural productivity and equipment reliability.



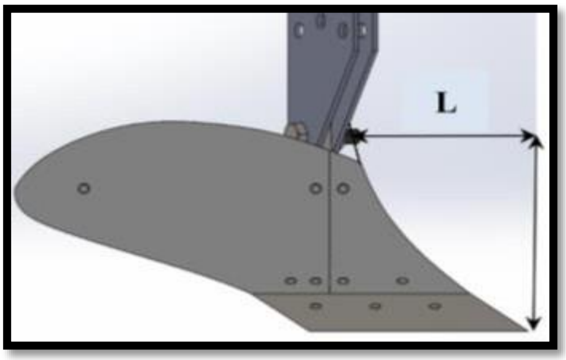


Figure 2: 3D Geometry of Plough **Figure 3: Front View of The Bottom**

MODELING THE MOLDBOARD PLOW.

The various components of the moldboard plow (such as the mast, brace, crossbar, toolbars, standard, heel, landside, share, and moldboard) were accurately modeled and assembled using SolidWorks, adhering to real-world dimensions. Key geometric parameters of the moldboard, including its steepness (L to H ratio), soil turning angle (β), angle of share point relative to the direction of motion (γ), and share length, were incorporated into the simulation, as depicted in FIG The curvature of the simulated moldboard.

E. ANALYSIS OF PLOUGH

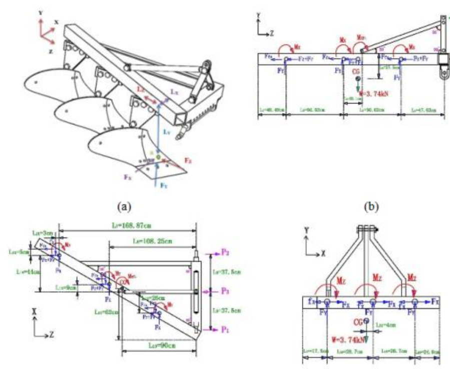
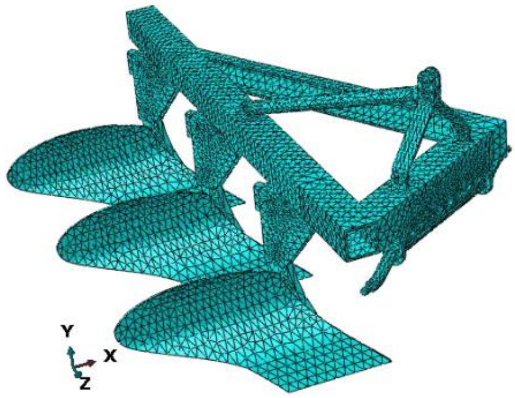



Figure 4: 3D geometry of moldboard plow **figure 5: Finite element mesh of moldboard plow**
and forces applied to the first bottom

This image shows a schematic diagram of a three-bottom moldboard plow, including its dimensions and the forces acting on it during operation. The image also includes a 3D model of the plow with a finite element mesh, which can be used for numerical simulations of the plow's performance. The diagram shows the plow in a static equilibrium condition, with the forces balanced. The numerical simulations can help to optimize the design of the plow for improved performance.

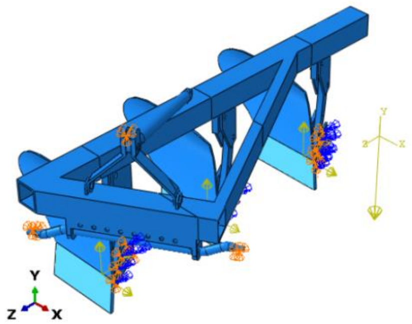
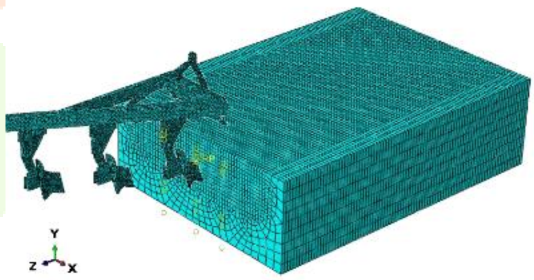
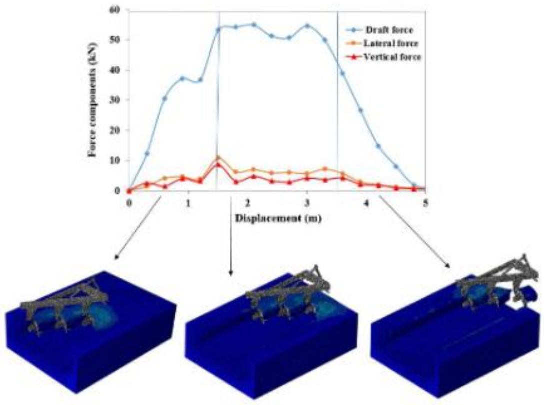



Figure 6: Loading and boundary conditions for simulation **Figure 7: Finite element mesh (FEM) of soil box**

The image shows a graph of the force required to push a three-bottom moldboard plow through soil at different depths. The force required increases as the plow depth increases, due to the increased resistance from the soil. The graph also shows the effect of different plow angles on the force required. A smaller plow angle requires less force, but may not turn over the soil as effectively. The graph can be used to optimize the plow depth and angle for a given soil type and tractor power. The data points in the graph are likely the result of physical experiments or numerical simulations.



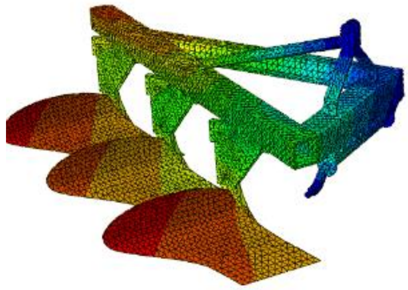


Figure 8: Soil Cutting Process and Tillage Force for Moldboard Plow Figure 9: Displacementof simulated moldboard plow at working depth and speed

The image shows a simulation of a plow digging into the ground. The graph on the left shows the forces exerted by the plow as it moves through the soil. The three different colored lines represent the draft force, lateral force, and vertical force. The images on the right show the plow at different stages of the simulation, with the color of the plow indicating the amount of stress on the plow. The color of the plow changes from blue to red as the stress increases.

V. RESULT AND DISCUSSION

Table 2. Results of plow draft force obtained from FEM and Godwin model for different soil conditions

Soil condition	Working depth (m)	Plowing speed (m s^{-1})	FEM-simulated draft (kN)	Analytical calculated draft (kN)
Loose soil	0.15	1	4.35	**7.30**
		2	5.03	**8.37**
		3	5.97	**10.15**
	0.3	1	10.84	**16.71**
		2	12.86	**18.85**
		3	17.05	**22.41**
Compacted soil	0.15	1	18.80	**20.35**
		2	19.71	**21.83**
		3	21.13	**24.31**
	0.3	1	39.65	**43.66**
		2	40.49	**46.63**
		3	45.05	**51.58**
Very compacted soil	0.15	1	22.81	**23.15**
		2	24.09	**24.76**
		3	25.70	**27.46**
	0.3	1	50.37	**49.52**
		2	54.06	**52.75**
		3	**54.93**	**58.14**

This table presents data on the forces exerted on a plow operating at different working depths and speeds. The forces are measured in three different directions: lateral, vertical, and draft. Here's a detailed breakdown of each column and its significance:

1. Working depth (m): This column indicates the depth at which the plow is working in meters. The depths given are 0.15 m, 0.2 m, 0.25 m, and 0.3 m.
2. Speed (m s^{-1}): This column shows the speed of the plow in meters per second. The speeds tested are 1 m/s, 1.5 m/s, 2 m/s, 2.5 m/s, and 3 m/s.
3. Plow lateral force (kN): This column represents the lateral force acting on the plow in kilonewtons (kN). The lateral force is the force acting perpendicular to the direction of travel of the plow.
4. Plow vertical force (kN): This column indicates the vertical force exerted on the plow in kilonewtons (kN). The vertical force is the force acting upward or downward on the plow.
5. Plow draft force (kN): This column shows the draft force acting on the plow in kilonewtons (kN). The draft force is the force required to pull the plow forward through the soil.

Observations:

Increasing Depth: As the working depth increases from 0.15 m to 0.3 m, all the forces (lateral, vertical, and draft) increase for a given speed. This indicates that deeper plowing requires more force.

Increasing Speed: For each working depth, increasing the speed from 1 m/s to 3 m/s also results in an increase in all three types of forces. Higher speeds require more power to maintain the same depth of plowing.

Detailed Calculation:

At a working depth of 0.15 m and a speed of 1 m/s:

- The plow lateral force is 4.12 kN.
- The plow vertical force is 1.69 kN.
- The plow draft force is 22.81 kN.

At a working depth of 0.3 m and a speed of 3 m/s:

- The plow lateral force is 10.76 kN.
- The plow vertical force is 8.65 kN.
- The plow draft force is 54.93 kN.

Summary:

The table illustrates how the forces required for plowing increase with both depth and speed. This information is crucial for designing and operating plowing equipment, ensuring that the machinery can handle the forces encountered during operation.

Working depth (m)	Plowing speed (m s^{-1})	Maximum Von-Mises stress (MPa)	Maximum nor- mal stress (S_{11}) (MPa)	Maximum shear stress (S_{12}) (MPa)	Maximum displacement in direction of draft force (mm)	Maximum normal strain (E_{11}) (mm/mm)
0.15	1	4.24×10^{2}	-1.24×10^{2}	-6.4×10^{1}	-9.98×10^{-1}	-8.78×10^{-4}
0.3	3	8.68×10^{2}	-2.97×10^{2}	-1.5×10^{2}	-1.88	-2.1×10^{-3}

Detailed Explanation:

At a working depth of 0.15 m and a speed of 1 m/s:

- **Maximum Von-Mises stress:** 4.24×10^2 MPa (424 MPa)
- **Maximum normal stress (S_{11}):** -1.24×10^2 MPa (-124 MPa)
- **Maximum shear stress (S_{12}):** -6.4×10^1 MPa (-64 MPa)
- **Maximum displacement in the direction of draft force:** -9.98×10^{-1} mm (-0.998 mm)
- **Maximum normal strain (E_{11}):** -8.78×10^{-4} mm/mm (-0.000878 mm/mm)

At a working depth of 0.3 m and a speed of 3 m/s:

- **Maximum Von-Mises stress:** 8.68×10^2 MPa (868 MPa)
- **Maximum normal stress (S_{11}):** -2.97×10^2 MPa (-297 MPa)
- **Maximum shear stress (S_{12}):** -1.5×10^2 MPa (-150 MPa)
- **Maximum displacement in the direction of draft force:** -1.88 mm
- **Maximum normal strain (E_{11}):** -2.1×10^{-3} mm/mm (-0.0021 mm/mm)

Observations:

- **Stress Increase with Depth and Speed**: The maximum Von-Mises stress, normal stress, and shear stress all increase significantly when the working depth and speed are increased from 0.15 m at 1 m/s to 0.3 m at 3 m/s. This indicates that deeper and faster plowing leads to higher stresses within the plow material.
- **Displacement and Strain**: Both the maximum displacement in the direction of the draft force and the maximum normal strain also increase with higher depth and speed, suggesting greater deformation of the plow under more strenuous working conditions.

Summary:

The table provides a clear indication of how different plowing conditions affect the mechanical stresses and deformations experienced by the plow. Increased working depth and speed result in higher stresses (Von-Mises, normal, and shear) and greater displacement and strain. This information is crucial for designing plowing equipment to withstand the forces encountered during operation and to ensure durability and performance under varying field conditions.

VI. CONCLUSION

In this study, the structural analysis of a three-bottom reversible mounted moldboard plow was carried out to find the parts which need to be optimized in design. Soil resistance forces were simulated with a plow-soil interaction FEM model, validated by the analytical model.

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