Chapter 12
Conceptual Design and Structural Analysis of a Multipurpose Agricultural Robot

Mervin Joe Thomas, Rekala Sai Bharani Kumar Goud, Nagamalla Jayaprakash, and Santhakumar Mohan

Abstract Modern farmers face several challenges in meeting the food needs of the increasing population growth. In order to meet the growing demand without compromising on the quality and quantity within available constraint spaces of farming, they must transform from conventional methods to precision agriculture, reducing direct human intervention. The advancements in agricultural operations from traditional to technological methods improve efficiency and offer a safer work environment. This paper focuses on the preliminary conceptual design and working of a low-cost all-terrain agricultural robot suitable for small/medium-scale farmers. The robot is designed to perform two individual operations—transplanting and weed removal. A brief description of the various components used to perform the two operations is highlighted in this paper.

12.1 Introduction

Recent times have shown a drastic transition from manual operations to technological intervention to overcome the challenges faced by modern farmers. The significant difficulties include high operational and production costs, environmental impacts, reduced farming grounds, lack of available labour and livestock, and plant diseases. Besides manual operations with sensitive plants, health concerns during the direct harvest of edible fruits/vegetables and fatigue due to monotonous, repetitive tasks

M. J. Thomas (✉) · R. S. B. K. Goud · N. Jayaprakash · S. Mohan
Department of Mechanical Engineering, Indian Institute of Technology, Palakkad 678623, India
e-mail: mervinjoethomas@iptif.tech

S. Mohan
e-mail: santhakumar@iitpkd.ac.in

M. J. Thomas
Post Doctoral Fellow, IIT Palakkad Technology IHub Foundation, Palakkad, India

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worsens the situation. This reason has directed researchers towards precision agriculture, which involves grouping robotics, Artificial Intelligence (AI) and the Internet of Things (IoT) in farming [1]. Nowadays, agricultural robots perform operations such as cultivation [2], pest [3] and weed control [4], inspection [5], and harvesting [6]. However, in the current scenario, agricultural robots exhibit drawbacks like high initial costs, low operational efficiency, bulky and complex mechanisms fitted with large sprayers for weed control [7]. In order to ensure a high yield and good quality harvest, weed control is critical. However, the challenge here is that the weeds exist in random patterns. Therefore, it is necessary to remove or retard the growth of the weeds without affecting the nearby plants. This very reason motivates researchers to devise novel designs to ensure precision.

Transplanting is a process of planting seedlings from containers grown in nurseries at equal spacing and desired depths. Manually performing this operation is a labour-intensive and time-consuming process. On the other hand, weeds' growth affects plants' growth, thereby compromising yield. The traditional and effective way to remove weeds is by eradicating and gathering them by hand. This manual process is, however, very monotonous, time-consuming and involves high labour costs. Similarly, spraying fertilizers or herbicides in bulk to control weed growth is hazardous to the plants and leads to much wastage. Besides, herbicides at undesired locations may gradually create problems like skin rashes and reduce soil quality, making it impotent [8]. Therefore, this paper presents a robot mechanism to perform transplanting operations and weed removal similar to hand-weeding. The robot is designed to be robust and adaptable to varying climatic conditions, removing weeds of different shapes and patterns. With this technology, the weeding process can be carried out without disturbing the desired crop.

This paper is organized as follows: Sect. 12.2 describes the robot architecture and conceptual design of the proposed robot mechanism. The robot's working in transplanting and weeding modes are detailed in Sect. 12.3. Section 12.4 explains the structural analysis results of the robot structure. Finally, a brief summary of this work and the scope for future work are given in Sect. 12.5.

12.2 Robot Architecture and Conceptual Design

This section describes the conceptual design of the proposed robot mechanism. The robot consists of a cart used in common for transplanting and weeding operations. Figure 12.1a, b show the robot's CAD model in both configurations. Since transplanting and weed operations happen at two instants of farming, the top portion of the robot can be changed as per the needs. The cart is made using an Aluminium T-slot frame. The cross-section of the frame is a double profile with six T-slots. The frames are connected using gussets. Gussets are used to hold the aluminium frame in a fixed position. This component permits easy assembly and disassembly. The robot base consists of four wheels powered by two motors on either side of the cart on the T-slot frame. The motors are connected to the wheels using a belt drive. The

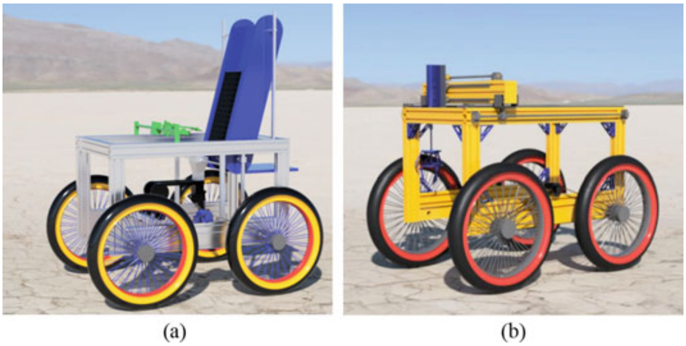


Fig. 12.1 CAD model of the proposed robot in **a** transplanting mode; and **b** weeding mode

following two subsections describe the transplanting and weeding mechanisms used in the proposed robot.

12.2.1 Transplanting Mechanism

The transplanting mechanism consists of three major components. The first component is the seedling tray with a holder. The seedling tray contains the seedlings that are to be planted. The seedling tray has fifteen rows and seven columns in the proposed design, with a total capacity to hold 105 seedlings.

Figure 12.2a shows the seedling tray with holder. The seedling tray holder contains a belt on which the seedling tray is placed. The seedling tray holder moves horizontally when the gripper takes a seedling from the seedling tray. When an entire row of seedlings is completed, the belt on which the seedling tray is placed rotates such that the seedling tray moves down by one row. The seedling tray holder moves horizontally using the lead screw mechanism powered by a stepper motor. The second major component is the gripper. The gripper is placed such that when it is in the extended position, it reaches the seedling in the seedling tray, and when it goes into the retracted position, it plucks the seedling from the seedling tray and drops it into the funnel-shaped component. Figure 12.2b shows the proposed gripper. The gripper moves from the retracted to the extended position using the x-bar mechanism powered by a motor. The rings placed on the needles act as sliders, as shown in Fig. 12.2c. When the rings move forward, the needles will move away from each other. When the rings move backwards, the needles move towards each other and vice-versa. A stepper motor powers the slider-crank mechanism. The third major component is the planting mechanism shown in Fig. 12.2d, which plants the seedlings into the soil that the gripper drops.

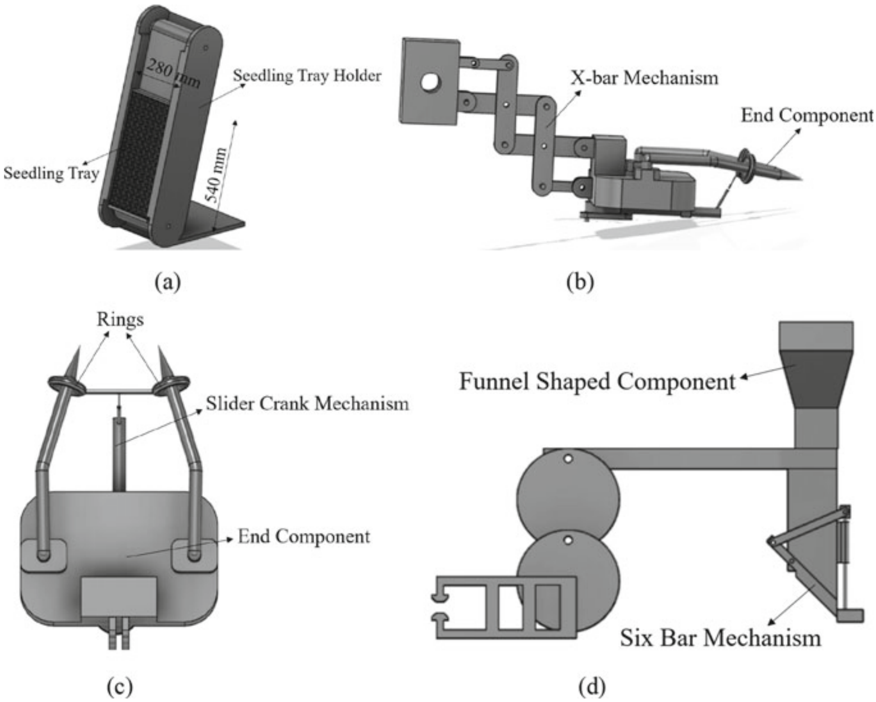


Fig. 12.2 Transplanting mechanism components **a** seedling tray with holder; **b** gripper; **c** end component; and **d** planter

12.2.2 Weeding Mechanism

The weeding mechanism consists of an additional Aluminium rail placed laterally over the cart to which the gripper and slider are attached. This rail can be translated longitudinally using the ball screw mechanism placed along the longitudinal rail of the cart on either side. Three ball screws are used in the design for the translational motion of the components. The ball screw transforms the rotational motion into linear motion. Figure 12.3a shows the CAD model of the ball screw assembly. The rail is mounted on ball-bearing carriages, allowing smooth rail translation motion. The ball-bearing carriages are guided by guide rails placed on T-slots in the cart. A slider is attached to the lateral rail, which helps the gripper move vertically, reaching weed roots. The slider is translated laterally along the rail with the help of a ball-screw mechanism. As shown in Fig. 12.1b, telescopic slides are mounted onto the lateral frame using ball-bearing carriages and guideways. Figure 12.3b shows a close-up view of the telescopic slides. The gripper shown in Fig. 12.3c is mounted on the telescopic slides to adjust the heights as per requirements. The end effector is a three-fingered parallel gripper.

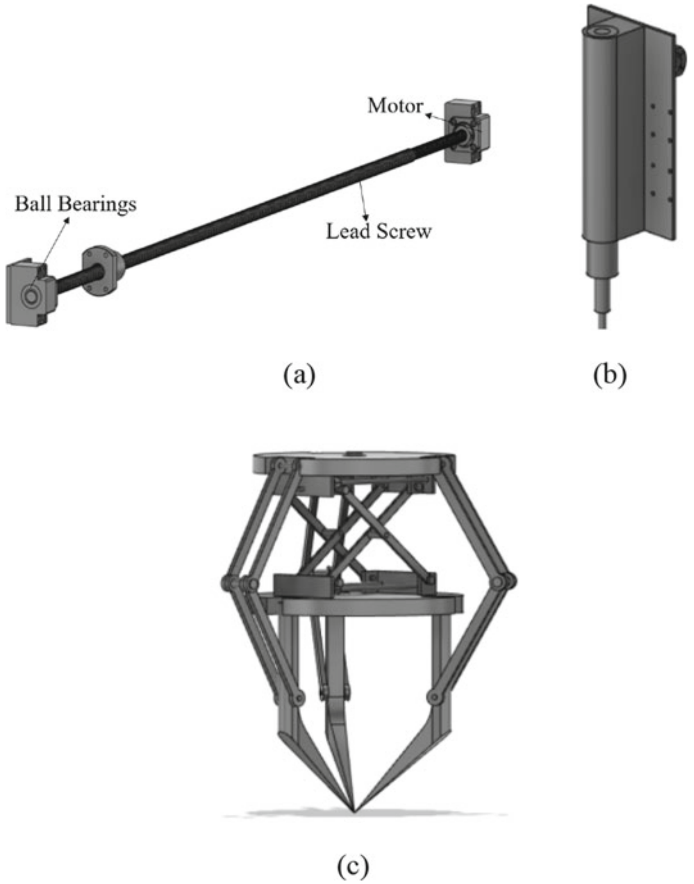


Fig. 12.3 Weeding mechanism components **a** ball screw assembly; **b** telescopic slides; and **c** end effector gripper

12.3 Working

This section describes the robot's working during the transplanting and weeding modes. The mobile cart is operated similarly to the tiller truck mechanism. This mechanism permits them to take sharper turns by manoeuvring the rear wheels. As explained earlier, transplanting is planting seedlings into the soil. The mobile robot base will have the components explained in Sect. 2.2(a) during the transplanting mode. Figure 12.4a shows a line diagram of the transplanting mechanism with the direction of motion of each component. The seedlings produced in seedling trays from the nursury are placed on the seedling tray holder. The seedling tray holder moves horizontally using the leadscrew mechanism, and the seedling tray is pushed downwards via belt drive. The gripper from the reverted position moves to the extended position using the X-bar mechanism. As the gripper moves towards the extended

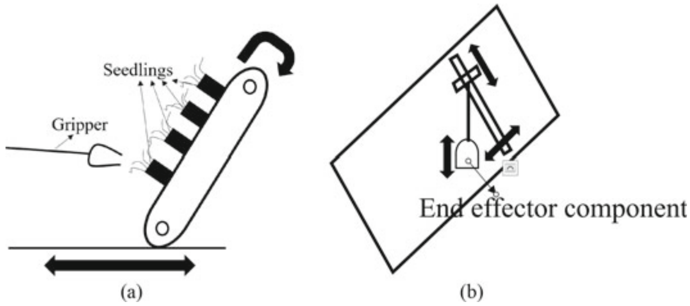


Fig. 12.4 Schematic line diagram **a** transplanting mechanism, and **b** weeding mechanism

position, the needles of the gripper are made closer and the gripper gets hold of the seedling in the tray. On retracting the gripper, the seedling is pulled out from the tray. Then the needles of the gripper are moved away, resulting in the seedling falling into the funnel-shaped component and then dropping into the planter. The planter can move vertically up and down. The planter takes the seedling dropped by the gripper and moves it into the soil. When the planter moves into the soil, the slider at the bottom of the planter moves upward due to the force applied by the ground, resulting in the bottom of the planter to open. This further drops the seedling into the hole made by the planter mechanism. This completes one cycle of the seedling process. The cart then moves to the next seedling position. When all the seedlings in a row are planted, the belt on which the seedling tray is placed rotates, causing the seedling tray to move a row down.

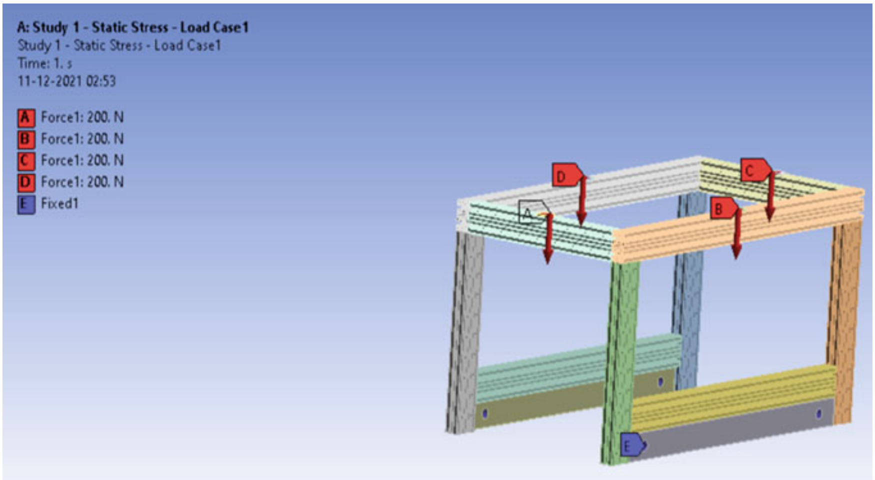
Ball-screw mechanisms are used for lateral and longitudinal end-effector movement during the weeding process. The sliders attached to the lateral aluminium frame will help the gripper adjust its height vertically to remove weeds from roots by penetrating the soil. The sliders would also protect the gripper from any obstacle on the ground. The three-fingered, self-centred, parallel gripper is operated parallel using a scissor lifting mechanism. A lead screw mechanism is used to slide the scissor lift mechanism. Figure 12.4b shows the line diagram of the gantry mechanism used for the weeding process.

12.4 Static Structural Analysis

This section explains the static structural analysis results of the mobile cart on which all the other components are placed. The structural analysis is performed using the ANSYS Workbench software package. The simulation study is done for two cases—Case 1: A static load of 200 N is applied to the top of the cart on each frame (Fig. 12.5a), and Case 2: A static load of 1000 N is applied at the centre of the cart (Fig. 12.5b. The material assigned for the analysis is Aluminium 6061 T6 hot formed. The parameters assigned for the simulation study are listed in Table 12.1. The element type chosen for the study is tetrahedral. The total number of elements and nodes in the study were 213,863 and 1,382,681, respectively. Figures 12.6 and 12.7 show the simulation results for the two cases described earlier. Table 12.2 lists the results obtained from the simulation study for the two cases. It is clear from the simulation results that the stresses and the deformation induced within the frame are within the safe limits and, therefore, can further proceed for the prototype fabrication for proof of concept. The maximum deformation induced in the frame is 0.08 mm, and the maximum Von-Mises stress induced is 14.442 MPa.

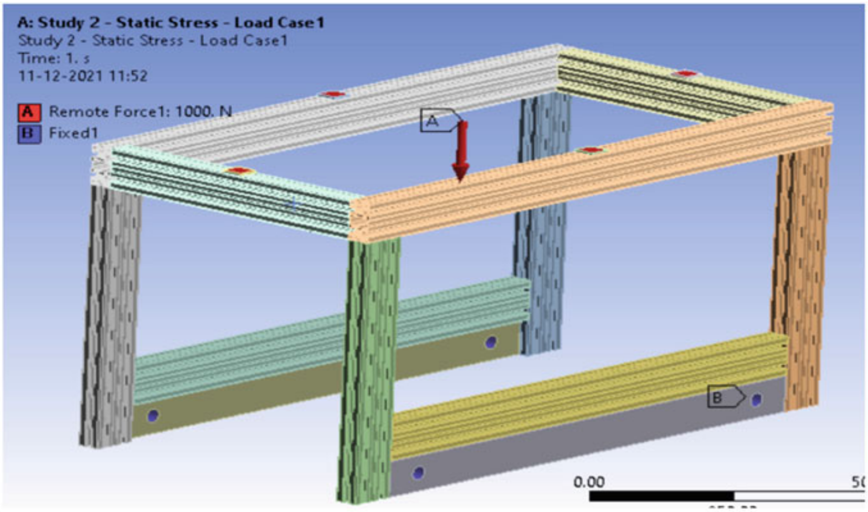
12.5 Conclusion and Scope for Future Work

This paper explains the conceptual design and preliminary results of an agricultural robot for transplanting and weed removal operations. A detailed description of the individual components of the robot when in use for the two modes is described. The static structural analysis is carried out for the robot base for two loading conditions. The results indicate that the design is safe and can be further used for hardware fabrication. Additionally, the robot will be equipped with a basic level of autonomy to make the process more user-friendly for the farmer. Also, incorporating solar technology for power and Bluetooth connectivity for remote control can enable untethered operations on the ground.



(a)

Fig. 12.5 Structural analysis loading conditions **a** Case 1; and **b** Case 2

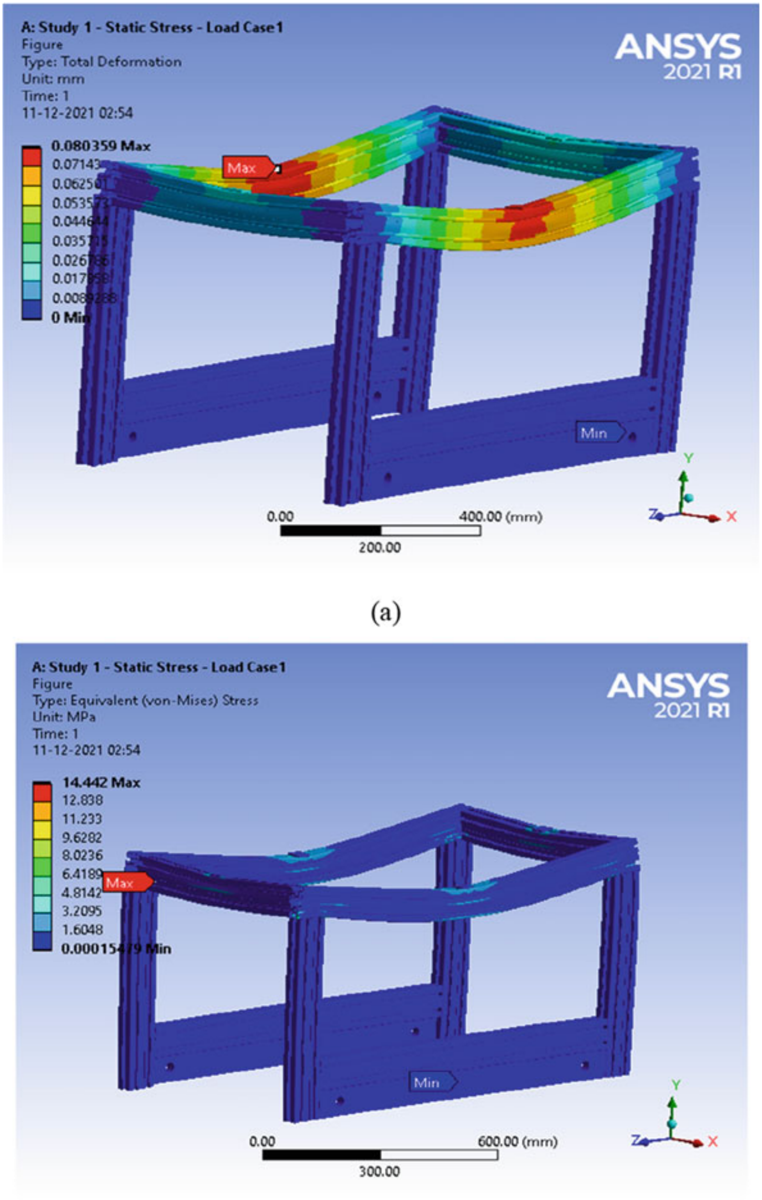


(b)

Fig. 12.5 (continued)

Table 12.1 List of parameters assigned for the simulation study

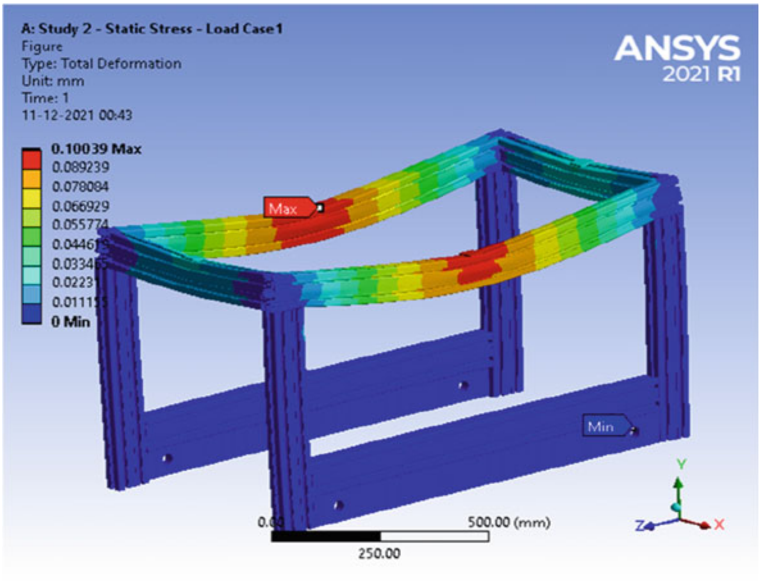
S. No	Parameter	Magnitude
1	Density (kg/mm^3)	2.7e−6
2	Thermal conductivity (W/mm C)	0.167
3	Specific heat (mJ/kg C)	8.96e5
4	Youngs modulus (MPa)	72,700
5	Poisson's ratio	0.33
6	Bulk modulus (MPa)	71,275
7	Shear modulus (MPa)	27,331
8	Ultimate tensile strength (MPa)	340
9	Yield strength (MPa)	313



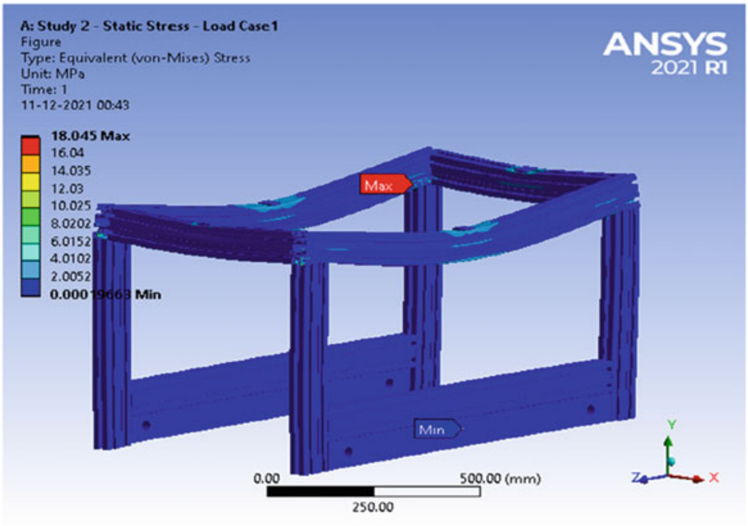
(a)

(b)

Fig. 12.6 ANSYS simulation results for Case 1 **a** total deformation; and **b** Von-Mises stress



(a)



(b)

Fig. 12.7 ANSYS simulation results for Case 1 **a** total deformation; and **b** Von-Mises stress

Table 12.2 Simulation results

Case 1	Total deformation (mm)	0.08
	Von-Mises stress (MPa)	14.442
Case 2	Total deformation (mm)	0.10039
	Von-Mises stress (MPa)	18.045

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