Journal of Tropical Agriculture 60(2): 273-281, 2022

Short Communication

Static analysis of a 'sit and stand' type coconut tree climber

V. Pooja, M.K. Shamin and P.R. Jayan*

Kelappaji College of Agricultural Engineering & Technology, Kerala Agricultural University, Tavanur - 679 573, Kerala, India

Received 08 June 2022; received in revised form 11 November 2022; accepted 03 December 2022

Abstract

Coconuts are harvested by climbing the tree and cutting the nuts by hand. Manually climbing up and down the tree is hazardous and tedious. A few models of mechanical coconut tree climbers are available to overcome these drawbacks. Testing the mechanical strength and stability of the coconut tree climbers is necessary to ensure their safe performance under working conditions. The static analysis of the top and bottom frames of the farmer's model of a sit and stand type climber was carried out separately using the ANSYS 15.0 software. Analysis was carried out for various loads of 400, 500, 600, 700, 800, 900, and 1000 N, respectively. The static analysis was interpreted with the equivalent (Von Mises) stress, equivalent elastic strain, and total deformation. The results showed that the Von Mises stress increased as the load increased. A maximum Von Mises stress of 1.5608×10^{8} Pa and 6.2431×10^{7} Pa, respectively were observed at loads of 1000 N and 400 N for the top frame. A maximum equivalent elastic strain of 7.845×10^{-4} and 3.138×10^{-4}, respectively were observed at loads of 1000 N and 400 N for the top frame. The minimum factor of safety of 1.6 and 4.0 respectively at loads of 1000 N and 400 N for the top frame and 1.3 and 3.2, respectively at loads of 1000 N and 400 N for the bottom frame was observed.

Keywords: ANSYS, Factor of safety, Sit and stand type coconut tree climber, Static analysis, Von Mises stress**.**

The coconut palm (*Cocos nucifera*) is one of the most useful palms in the world. Every part of the palm is useful for humans for some purpose or the other (DebMandal et al., 2011). Therefore, the coconut palm is also called as 'Kalpavriksha', meaning the tree of heaven (Ahuja et al., 2014). Major coconut growing states in India are Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh. The largest area under the crop with 788000 ha which is 41.6% of national acreage and tops in terms of coconut production with total yield of 5,384 million nuts per year. The state holds the 6th position in terms of productivity, with a production of 6,990 coconuts per hectare (Thamban et al., 2016). Considering the area under cultivation of crops, coconut occupies the first place in Kerala from coir industry to coconut shell artefacts; coconuts bring many economic gains to the State.

The majority of coconuts are harvested by climbing the palm and cutting bunches down with knife. This process may seem simple but it is quite dangerous and time consuming. Normally skilled workers climb the palm to harvest the coconuts. Since coconut palms are very tall, any fall from the top of the palm can result in severe injury, even death.

When working with a coconut palm climber its material and construction is subjected to forces acted by the climbing person. Therefore, the designers and agricultural machinery manufacturers need to predict deformation and structural stress distributions on coconut palm climbers.

*Author for Correspondences: Phone: 9447301928, Email: jayan.pr@kau.in

Among the different available climbers, 'Chachoos Maramkeri (a farmer's model)' of 'sit and stand' type coconut climber was selected in the study. The climber (Fig 3.) consists of top and bottom frames fitted with adjustable wire ropes. The top frame is intended for the operator's comfortable seating, and the bottom frame supports the foot. While climbing, both frames can be moved upward alternately by means of combined actions of hand and leg. These actions will be just reversed while climbing down. The 95th percentile weight of the operator is about 1000N. Hence, both top and bottom frames were designed in such a way that it can carry a weight up to 1000N. The Structural steel was used for the fabrication of top and bottom frames. This climber's total weight, including top and bottom frames (Fig 1 and Fig 2) is 4.95 kg. Safety lock pins were provided for attaching wire ropes with the main unit which reduces the time for fitting or removing of the climber. Rubber bushes were provided for foot rest and foot holder as cushioning material.

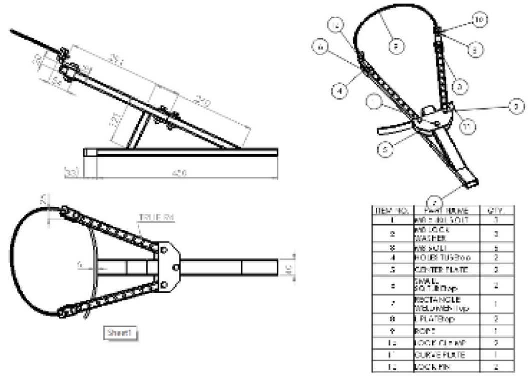


Figure 1. Top frame

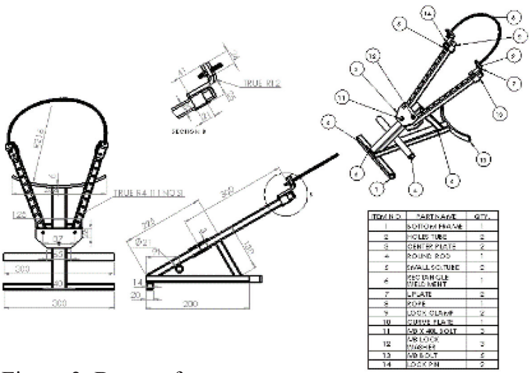


Figure 2. Bottom frame

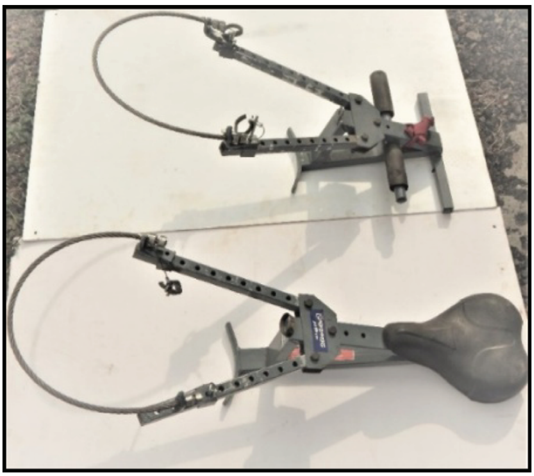


Figure 3. Farmer's model of a 'Sit and stand type coconut climber

The 3D modelling of the climber was carried out in Solidworks 13.0 software. In Solidworks, 3D models of each part can be designed and assembled easily and interference between components can be checked conveniently (Liao et al, 2011). Due to its powerful functions it become easy to learn and use the characteristics and is widely applied in mechanical designing. As this software is suitable for product development as it can shorten the product design cycle, improve design quality and reduce the cost involved. Hence it become one of the main stream software in mechanical design and modelling (Shahu 2017).

Using the FEM analysis software, the conditional behaviour of the structural components of the climber is to be simulated under load conditions. The 3-dimensional model of the climber was generated in Solidworks 13.0 software and then imported into ANSYS 15.0 software and analysed. The static analysis was conducted to get results of equivalent (Von Mises) stress, equivalent elastic strain, and total deformation. In post-processing, the results were analysed and interpreted. To interpret the results more efficiently under static analysis, the equivalent (Von Mises) Stress, equivalent elastic strain, and total deformation were separately

Table 1. Material properties of the structure steel

Properties	Values
Density (kg m^{-3})	7850
Coefficient of Thermal Expansion (°C^{-1})	1.2×10^{-5}
Specific Heat (J kg^{-1} °C^{-1})	434
Thermal conductivity (W m^{-1} °K^{-1})	60.5
Resistivity (Ω M)	1.7×10^{-7}
Compressive Yield Strength (Pa)	2.5×10^{8}
Tensile Yield Strength (Pa)	2.5×10^{8}
Tensile Ultimate Strength (Pa)	4.6×10^{8}
Young's Modulus (Pa)	2×10^{11}
Bulk Modulus (Pa)	1.6667×10^{11}
Shear Modulus (Pa)	7.6923×10^{10}
Poisson's Ratio	0.3

analysed for both top and bottom frames of the climber. The variable loads selected for the study are 400, 500, 600, 700, 800, 900, and 1000 N, assuming the weight of different human operators climbing the tree. The climber's strength and stability results were analysed and discussed for better design under safe operating conditions.

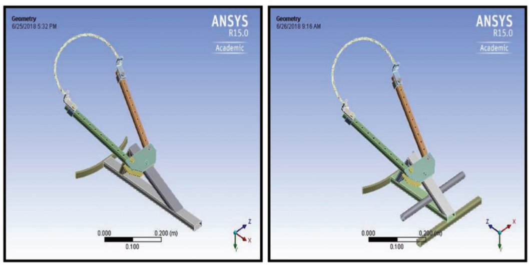
Pre-processing involves meshing, applying boundary conditions and material properties. Once the 3-D model is meshed, material properties are to be defined and applied to the meshed part. The material used for the construction of the top and bottom frames was structural steel, and its material properties are given in the Table 1.

The next step in the preprocessing is to apply boundary conditions to the 3-D model. The boundary conditions include applied loads and the details of fixed supports. Loads are usually defined as forces acting on a certain point, but can also be torques, pressures, temperatures, or even a velocity or acceleration, such as gravity acting on the unit. The analysis was hence carried out for the different probable weights of the operators separately for the top and bottom frames. A minimum weight (force) of 400 N and a maximum weight (force) of 1000 N for the operators were considered. It is assumed that major forces are acting on the sitting point of the climbers in the top frames and the foot rest point in the bottom frames. Fixed supports are the constraints that define how and where the structure is welded or bolted to stop the structure from flying structural off into space when a force is applied. These are directed to the software whose nodes are not allowed to move during the analysis. Also, the wire rope was considered as the fixed support as it restricts the climber from falling down the palm.

The next step in the FEA analysis is the generation of mathematical equations through a solver. A set of mathematical equations were generated for each node of the model. Every material has the maximum yield and ultimate strength. If the stress within a part exceeds the yield strength, it will not return to its original shape when the load is removed. If the stress exceeds the ultimate strength, the part will fracture and break. Ideally, the aim of this analysis is also to find the stresses within the parts of climbers that remain below or above the yield strength of the material.

Static analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response were assumed to vary slowly with respect to time. In this study, equivalent (Von Mises) stresses, equivalent elastic strain, and total deformation of both top and bottom frames if the climber was subjected to different loads of 400, 500, 600, 700, 800, 900, and 1000 N, respectively.

Total deformation is the vector sum of all directional displacements of the systems. Deformation results from ANSYS workbench is the total deformation



(Top frame) (Bottom frame)

Figure 4. Three dimensional models of the climber

or directional deformation. Both of them are used to obtain displacements from stresses. The main difference is that the directional deformation calculates the deformations in X, Y, and Z planes for a given structure. In total deformation, it gives a square root of the summation of the square of x-direction, y-direction, and z-direction means vector sum of all directional displacements of the structure. To avoid unforeseen failure, the mechanical designs often undertake the concept of a safety factor to reduce the probability of failure increase reliability. In static analysis the safety factor is the ratio between the yield strength of the material and equivalent (Von Mises) stress in a part. Essentially, the factor of safety is how much stronger the system is than it needs to be for an intended load.

Static analysis

The static analysis was carried out separately for the top and bottom frames of the climber at different loads. The equivalent (Von Mises) stress, equivalent elastic strain, and total deformation were found using ANSYS 15.0 software at each load.

Top frame

The top frame was made of structural steel. The boundary conditions are fixed. The meshed model has a total of 50951 elements and 136493 nodes. The structural steel is ductile so Von Mises stresses were observed. The Von Mises stresses of the top frame are shown in Fig 5 (a) to (g) at various loads. A maximum Von Mises stress of 1.5608×10^8 Pa was observed at a load of 1000 N, whereas the maximum Von Mises stress was only 6.2431×10^7 Pa when the load was 400 N. The maximum Von Mises stress was observed in the lock pin and the minimum in the rope. From the Table 2 it is observed that as the load was increased from 400 to 1000 N, the Von Mises stress were also increased. Equivalent elastic strain is the recoverable elastic deformation of a solid if the stress is removed. The equivalent elastic strain of the top frame of the climber is illustrated in Fig 6 (a) to (g) under various loads. The maximum equivalent elastic strain at 400 N and 1000 N were 3.138×10^{-4} and 7.845×10^{-4}

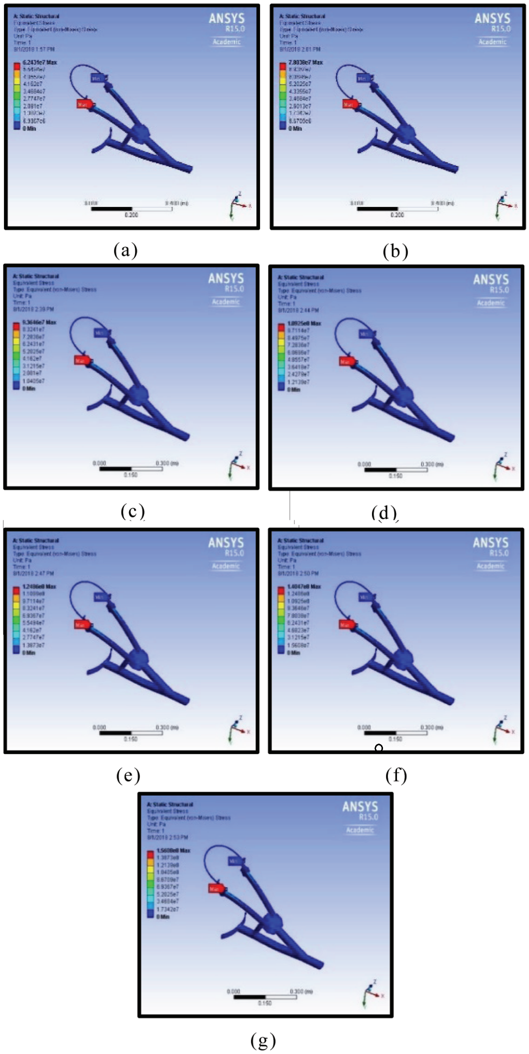


Figure 5. Equivalent (Von Mises) stress of the top frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

Table 2. Static analysis of the top frame of the climber

Load (N)	Equivalent (Von Mises Stress) (Pa) (max.)	Equivalent Elastic Strain (m/m) (max.)	Total deformation (m) (max.)
400	6.2431×10^7	3.138×10^{-4}	6.8534×10^{-5}
500	7.8038×10^7	3.9225×10^{-4}	8.5667×10^{-5}
600	9.3646×10^7	4.707×10^{-4}	1.028×10^{-4}
700	1.0925×10^8	5.4915×10^{-4}	1.1993×10^{-4}
800	1.2486×10^8	6.276×10^{-4}	1.3707×10^{-4}
900	1.4047×10^8	7.0605×10^{-4}	1.542×10^{-4}
1000	1.5608×10^8	7.845×10^{-4}	1.7133×10^{-4}

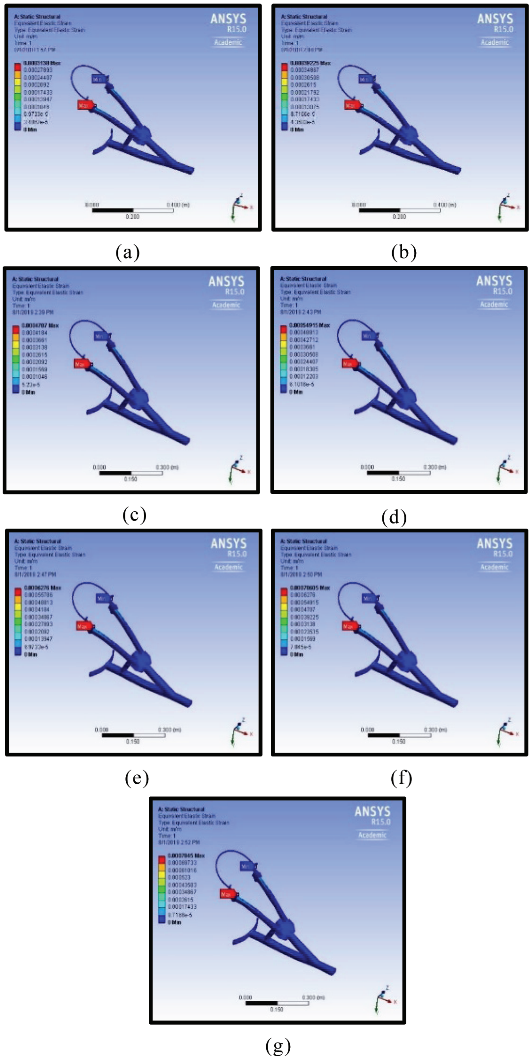


Figure 6. Equivalent elastic strain of the top frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

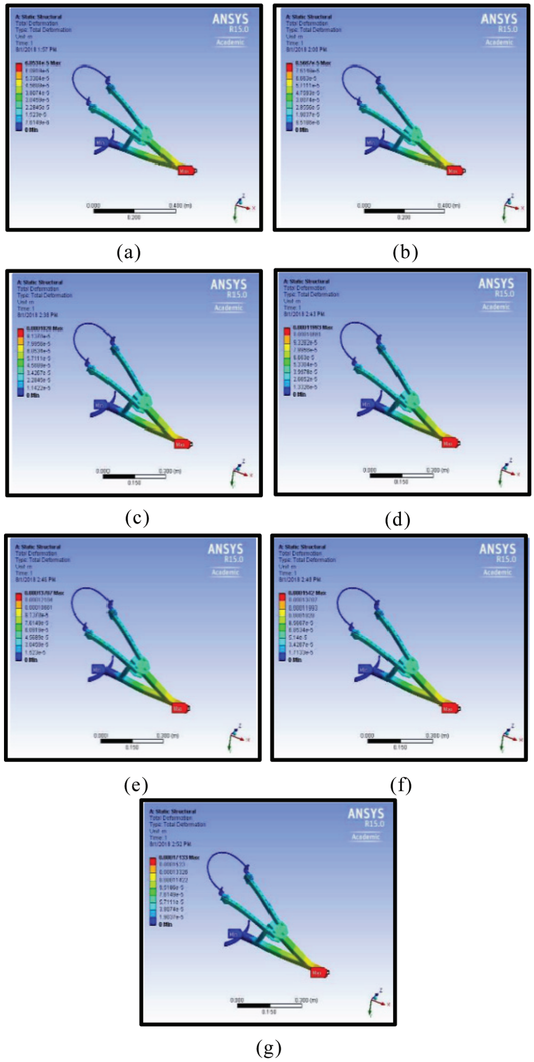


Figure 7. Total deformation of the top frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

respectively. The maximum strain occurs on lock pin and the minimum on the rope. From Table 2 it is observed that as the load increased from 400 to 1000 N, the equivalent elastic strain was also increased.

The total deformation of the top frame of the climber is illustrated in Fig 7 (a) to (g) under various loads. The maximum total deformation at 400 N and 1000 N were 6.8534×10^{-5} m and 1.7133×10^{-4} m respectively. The maximum deformation occurs on the rectangle plate and the minimum on the curve plate. From Table 2 it is observed that as the load increased from 400 to 1000 N, the total deformation was also increased. The factor of safety of the top frame at various loads from 400 N to 1000 N loads is given in Table 3. The factor of safety will be > 3 at 400 and 500 N loads, > 2 at 600 and 700 N loads, and > 1 at 800 to 1000 N loads (Fig 11).

To determine the structural safety of the climber under the loads of 400 N to 1000 N, the equivalent

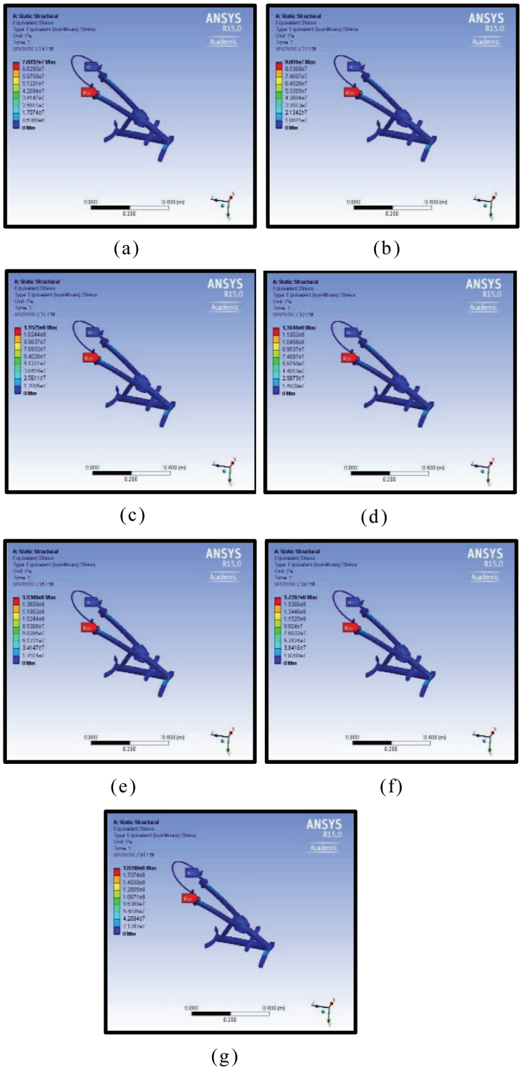


Figure 8. Equivalent (Von Mises) stress of the bottom frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

Table 3. Factor of safety of top frame of the climber

Load (N)	Equivalent (Von Mises) Stress(Pa)	Yield strength of the material (Pa)	Factor of safety
400	6.2431×10^7	2.5×10^8	4.0
500	7.8038×10^7	2.5×10^8	3.2
600	9.3646×10^7	2.5×10^8	2.7
700	1.0925×10^8	2.5×10^8	2.3
800	1.2486×10^8	2.5×10^8	2.0
900	1.4047×10^8	2.5×10^8	1.8
1000	1.5608×10^8	2.5×10^8	1.6

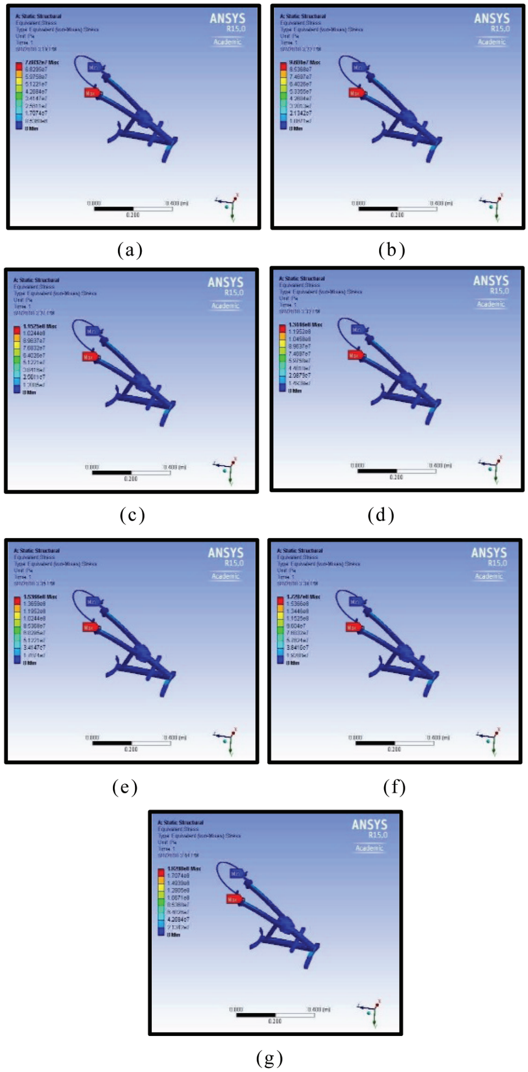


Figure 9. Equivalent elastic strain of the bottom frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

(Von Mises) stress values obtained from the static analysis were recorded. The yield strength of the material used in the fabrication of the climber is then taken from the material library of ANSYS 15.0.

The results in Table 2 and Table 3 indicate that, as the load on the climber increased the equivalent (Von Mises) stress, equivalent elastic strain and total deformation were also increased. The stress up to 1000 N was less than the yield strength of the

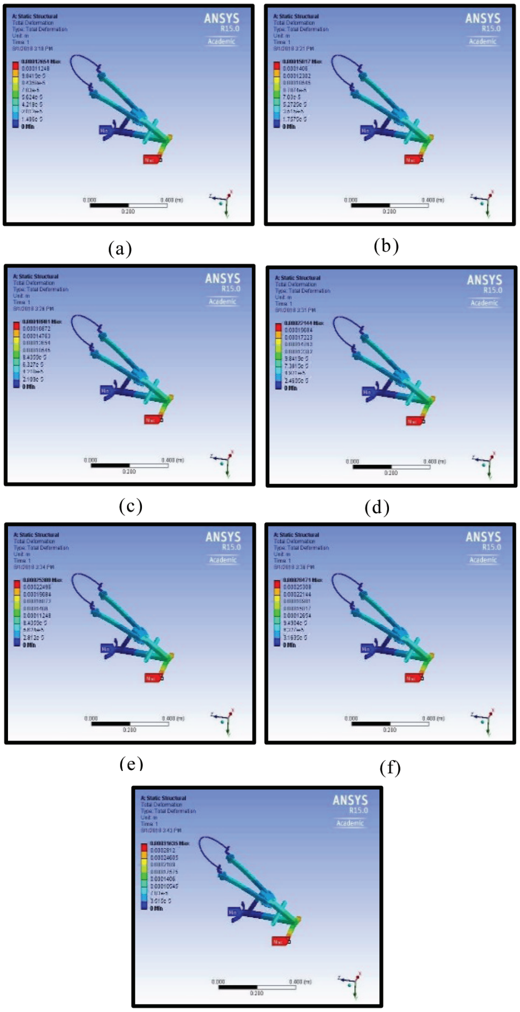


Figure 10. Total deformation of the bottom frame of the climber at loads of (a) 400 N, (b) 500 N, (c) 600 N, (d) 700 N, (e) 800 N, (f) 900 N and (g) 1000N

structural steel material i.e. 250 MPa. As the safety factor is more than one for all the cases then the failure will not occur. Hence the top frame of the climber is safe to operate under loads of 400 to 1000 N. The maximum stress was observed at the lock pin, hence this part is more prone to failure. To increase the load bearing capacity, a double locking system is suggested to secure safety in operation.

Bottom frame

The bottom frame is also made up of structural steel material. The meshed model of the bottom frame has 52056 elements and 153003 nodes. The Von Mises stresses of the bottom frame of the climber are shown in Fig 8 (a) to (g) at various loads. A maximum Von Mises stress of 1.9208×10^8 Pa was observed at a load of 1000 N. But the maximum Von Mises stress was only 7.6832×10^7 Pa when the load was 400 N. The maximum Von Mises stress was observed in the lock pin and the minimum in rope. From Table 4 it is observed that as the load increased from 400 to 1000 N, the Von Mises stresses also increased. The equivalent elastic strain of the bottom frame of the climber is illustrated in Fig 9 (a) to (g) under various loads. The maximum equivalent elastic strain at 400 N and 1000 N were 3.881×10^{-4} and 9.7025×10^{-4}, respectively. The maximum strain occurred on the lock pin and the minimum on rope. From Table 4, it is observed that, as the load increased from 400 to 1000 N, the equivalent elastic strain was also increased.

The total deformation of the bottom frame of the climber is illustrated in Fig 10 (a) to (g) under various loads. The maximum total deformation at 400 N and 1000 N were 1.2654×10^{-4} m and 3.1635×10^{-4} m respectively. The maximum deformation occurs on the bottom frame and the minimum on curve plate. From Table 4 it is observed that as the load increased from 400 to 1000 N, the total deformation was also increased. The factor of safety of the bottom frame of the climber at 400 N to 1000 N loads is given in the Table 5. The factor of safety will be > 3 at 400 N load, > 2 at 500 and 600 N loads, and > 1 at 700 to 1000 N loads(Fig 12).

Table 4. Static analysis of the bottom frame of the climber

Load (N)	Equivalent (Von Mises) Stress (Pa) (max.)	Equivalent Elastic Strain (m/m) (max.)	Total deformation (m) (max.)
400	7.6832×10^7	3.881×10^{-4}	1.2654×10^{-4}
500	9.604×10^7	4.8512×10^{-4}	1.5817×10^{-4}
600	1.1525×10^8	5.8215×10^{-4}	1.8981×10^{-4}
700	1.3446×10^8	6.7917×10^{-4}	2.2144×10^{-4}
800	1.5366×10^8	7.762×10^{-4}	2.5308×10^{-4}
900	1.7287×10^8	8.7322×10^{-4}	2.8471×10^{-4}
1000	1.9208×10^8	9.7025×10^{-4}	$3.1635 \text{ x } 10^{-4}$

Table 5. Factor of safety of bottom frame of the climber model

Load (N)	Equivalent (Von Mises) Stress (Pa)	Yield strength of the material (Pa)	Factor of safety
400	7.6832×10^7	2.5×10^8	3.2
500	9.604×10^7	2.5×10^8	2.6
600	1.1525×10^8	2.5×10^8	2.2
700	1.3446×10^8	2.5×10^8	1.8
800	1.5366×10^8	2.5×10^8	1.6
900	1.7287×10^8	2.5×10^8	1.4
1000	1.9208×10^8	2.5×10^8	1.3

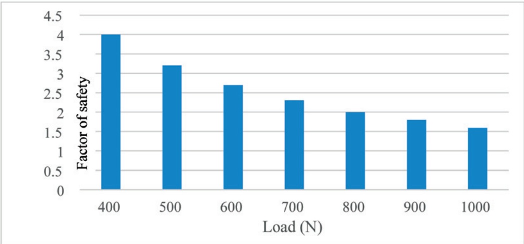


Figure 11. Factor of Safety w.r.t applied loads of the top frame of the climber

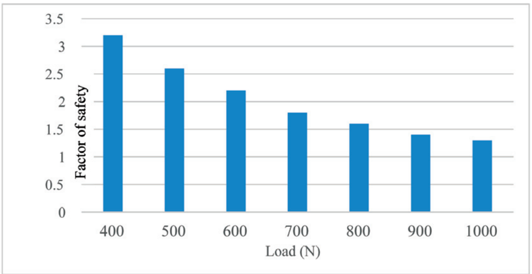


Figure 12. Factor of Safety w.r.t applied loads of the bottom frame of the climber

The results in Table 4 and Table 5 indicate that up to a load of 1000 N the top frame of the climber is safe to operate because the factor of safety is >1. To increase the load bearing capacity, a double locking system has to be provided as a safety measure.

Coconut palms are unbranched evergreen trees cultivated mainly for its nuts. The operations like harvesting of nuts and spraying pesticides need to be carried out at the crown, which requires labours to climb up the tree. Climbing of palm has been identified as laborious, hazardous, tedious and risky job. In order to make this job easy and to help the farmers in this regard, mechanical coconut climbers were developed. Strength and stability aspects of the top and bottom frames of the climber were analysed by 3-D modelling using Solid works 13.0 software and then meshing and applying boundary conditions in the ANSYS 15.0 software to conduct the static analysis.

In top frame of the climber model, the maximum Von Mises stress of 1.5608×10^8 Pa was observed at a load of 1000 N. But the maximum Von Mises stress was only 6.2431×10^7 Pa when the load was 400 N. The minimum factor of safety at 400 N and 1000 N were 4 and 1.6 respectively. The minimum factor of safety occurs in the lock pin. In the bottom frame of the climber, maximum Von Mises stress of 1.9208×10^8 Pa was observed at a load of 1000 N. But the maximum Von Mises stress was only 7.6832×10^7 Pa when the load was 400 N. The minimum factor of safety at 400 N and 1000 N were 3.2 and 1.3, respectively.

Acknowledgments

The authors would like to thank KAU, Dept. of Mechanical Engineering, NIT Calicut and FMTC (KCAET-KAU) for the facilities, system and financial support for the study and analysis of the coconut climber.

References

Ahuja, S.C., Ahuja, U. and Ahuja, S., 2014. Coconut-History, Uses, and Folklore. Asian Agric-History, 18(3).

DebMandal, M. and Mandal, S., 2011. Coconut (Cocos nucifera L.: Arecaceae): in health promotion and disease prevention. Asian Pac. J. Trop. Med., 4(3), pp.241-247.

Liao, X., Ma, X. and Zuo, Y., 2010, October. Design of rotary root stubble digging machine based on solidworks. International Conference on Computer and Computing Technologies in Agriculture (pp. 532-538). Springer, Berlin, Heidelberg.

Shahu, M. 2017. Design of Inclined Metering

Mechanism Based on Solid-works. Int. J. Eng. Res. Technol. 6(12): 70-73.

Thamban, C., Jayasekhar, S., Chandran, K. P. and Jaganathan, D. 2016. Coconut production in Kerala–trends, challenges and opportunities. Indian Coconut J., 1-7.