STRUCTURAL ANALYSIS AND CRITICAL DESIGN CRITERIA FOR FRONT END LOADING MACHINES BASED ON VECTOR MECHANICS

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Abstract - Mobile front end loaders are used throughout the world to perform important and dangerous manipulation tasks. The usefulness of these machines is greatly improved if they can utilize their mobile arms or links when they perform tasks. However the relative positions of the links influences the work efficiency of the machine. This project presents an approach to conduct structural analysis and design optimization of such machines based on vector mechanics. Based on the feedback and requirement was understood .The concepts are generated to design and analysis of the mechanism. A structural analysis is conducted to provide basic insights into the effects of the end load and crane configuration.The present research focuses on three major sections: static structural analysis, Kinematic analysis and Kinetic analysis for severe operating conditions. Results are correlated using empirical results.

Keywords – Structural Analysis, Static, Kinetic, Kinematic, DOF, Vector Mechanics, MATLAB, Front end loading machines.

INTRODUCTION

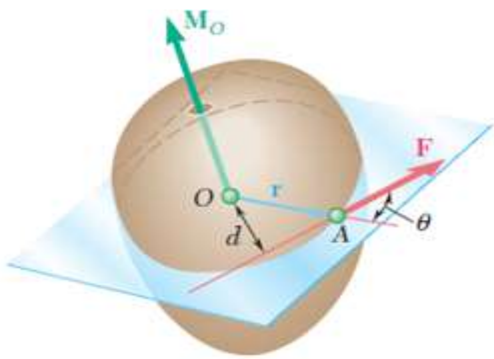
Mobile front end loading machines are used throughout the world to perform important and dangerous manipulation tasks. The usefulness of these machines is greatly improved if they can utilize their mobile arms or links when they perform the operations. However the relative positions of the links influences the work efficiency of the machine. In order to do this, these machines are designed in such a way that the whole structure of the machine is movable in many different ways, as are the various parts of the structure. There have been previous investigations of front end loaders. However, most previous work in this area has been limited to investigations of the front end loader’s stability during its operation. In general, mobile front end loaders are designed as boom cranes because of their structural advantages. Therefore, the analysis in this project concentrates on links of the machine. However, the methods and results can also be adapted to other types of cranes and mobile lifting machines.

This project presents an approach to conduct static force analysis of such machines based on vector mechanics. Based on the feedback and requirement was understood .The concepts are generated to analysis of the mechanism.

The static analysis is done with considering the self weight of links. Static analysis gives insights to the vector mechanics approach. Kinematic analysis is the basic step for the dynamic analysis. Kinetic analysis gives the critical design criteria for the machines.

1 VECTOR MECHANICS

The present work uses vector mechanics based approach in all the sections. Hence the concept the vector mechanics is explained briefly in this section. This approach uses the concept of vector algebra to solve the problems of mechanics. Three dimensional problems can be solved in a simple manner. The problems which are difficult to solve by using scalar methods can be solved easily by using this method. In some situation, the problems in statics may involve many force and moments in and around different directions which are difficult to imagine. At that situation, the concept of vectors are very useful to solve the problem. A vector can be defined as mathematical quantity which has both direction and magnitude and obeys parallelogram law. The example below explains the application of vector mechanics.



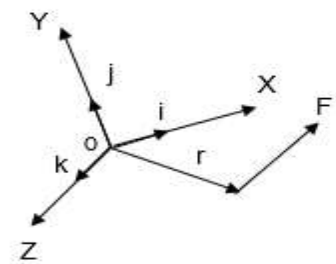


Figure 1 Moment of a force

It is needed to find the moment of a force F about point O. Normally, the moment is found out by multiplying force with perpendicular distance.

M_O=F x d =Force x distance.

This will give only magnitude of the moment of force about O. But in vector mechanics, the moment of a force about a particular point is defined as the cross product of position vector of point A with respect to point O and force. A coordinate system has to be taken at point O. Unit vectors in X, Y and Z directions are i, j and k respectively. The components of position vector r in X, Y, Z directions are l, m and n respectively. The components of force F in X, Y, Z directions are F_X, F_Y, F_Z respectively. Then moment of force F about point O is calculated as follows,

$M_O= r \times F= (li + mj + nk) \times (F_xi+F_yj+F_zk) = (m F_z -n F_y)i+(nF_x-lF_z)j+(lF_y -mF_x)k$

The final product gives the magnitude and direction moment of force.

In this section different cases regarding front end loading machines are solved and new approach has been established which will contribute to the design world. There are three sections which are 1) static analysis . 2) Kinematic analysis 3) kinetic Analysis

1) Static Analysis:

In this section , considered cases dealing with the equilibrium of structures made of several connected parts. These cases call for the determination not only of the external forces acting on the structure but also of the forces which hold together the various parts of the structure. From the point of view of the structure as a whole, these forces are internal forces.

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2) Kinematic Analysis:

In this section, the kinematics of rigid bodies will be considered. Investigation of the relations existing between the time, the positions , the velocities, and the accelerations of the various parts forming a rigid body. As will see, the various cases of rigid-bodies related to the analysis.

3) Kinetic Analysis:

The relations existing between the forces acting on a rigid body, the shape and mass of the body, and the motion produced. has been understood in the above sections, assuming then that the body could be considered as a particle, i.e., that its mass could be concentrated in one point and that all forces acted at that point. The shape of the body, as well as the exact location of the points of application of the forces, will now be taken into account. It also is concerned not only with the motion of the body as a whole but also with the motion of the body about its mass centre.

Approach will be to consider rigid bodies as made of large numbers of particles and to use the results obtained in the particle level for the motion of systems of particles. Specifically, two equations, $\sum \mathbf{F} = m\mathbf{a}$, which relates the resultant of the external forces and the acceleration of the mass center G of the system of particles, and Equation,

$\sum \mathbf{M}_G = \dot{\mathbf{H}}_G$, which relates the moment resultant of the external forces and the angular momentum of the system of particles about G.

1.1 Static Analysis

Problem definition:

The telescoping arm ABC is used to provide an elevated platform for construction workers as shown in figure2 . The workers and the platform together have a specified mass and have a combined centre of gravity located directly above C. For the position different position of luffing and slewing angle, determine the force exerted at B by the single hydraulic cylinder BD and the force exerted on the supporting carriage at A. Write a Mat lab programme for the above problem and calculate the Von mises stresses.

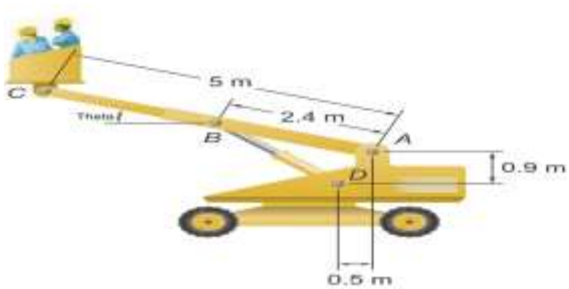

Figure 2 The telescopic boom

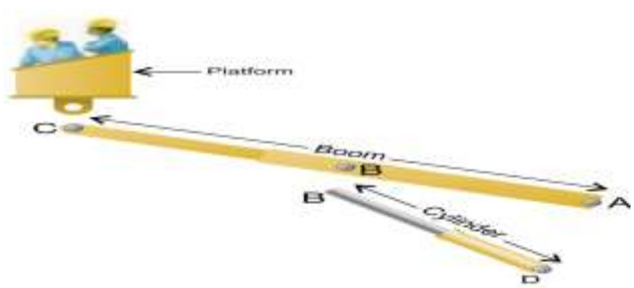

Figure 3 Problem Description

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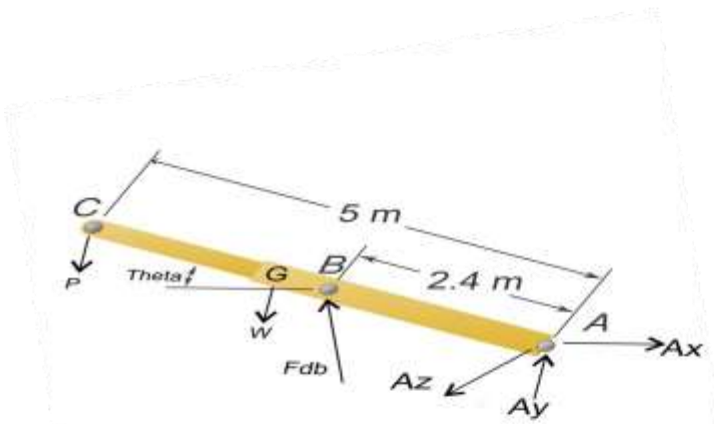
The telescopic boom machine has a boom which has the cylinder and plat form for the desired work. Boom has two degrees of freedom which are rotaion about Z axis known as Luffing angle (θ). Rotation about Y axis is known as Slewing angle (α). All rotations are measured in degrees.

Cylinder which is shown in figure 3 is the actuator for the desired rotation of the boom.

Vector Mechanics approach: Free body diagram is as shown in figure4 below



$\vec{F}_{db}$ is the cylinder force which acts in the direction of cylinder DB

$\vec{A}_x$, $\vec{A}_y$ and $\vec{A}_z$ are the rectangular components of hinge reactions at A.

$\overrightarrow{W}$ is the weight of the boom and $\vec{P}$ is the external load.

1.2 Kinematic and Kinetic Analysis

Problem Definition:

The arm AB of length 5 m is used to provide an elevated platform for construction workers. The arm AB is being raised or lowered at the constant rate ω_2 rad/s; simultaneously, the unit is being rotated about the Y axis at the constant rate ω_1 rad/s. Write the Mat lab programme to determine the velocity and acceleration of point B.

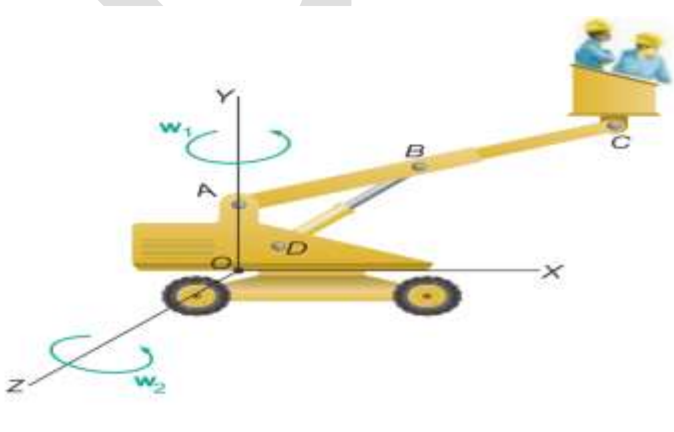


Figure 5 Problem description

Problem description: Telescoping boom is as shown in figure 5 . The kinematic analysis is done based on the vector mechanics To keep the plat form in required position the boom is rotated with rate so its necessary to do the kinematic analysis before moving to the kinetic analysis.

2 Force comparison with one of the commercial FEM software ANSYS

For one of the configuration and one of the problem , results are obtained from the vector mechanics approach and for the same configuration ANSYS based results.

Selected Configuration for the comparison: Load at the CG of the Platform is 10KN and luffing angle θ = 30° and slewing angle α = 10°. Mass of the boom is 436.8 Kg for the shown length

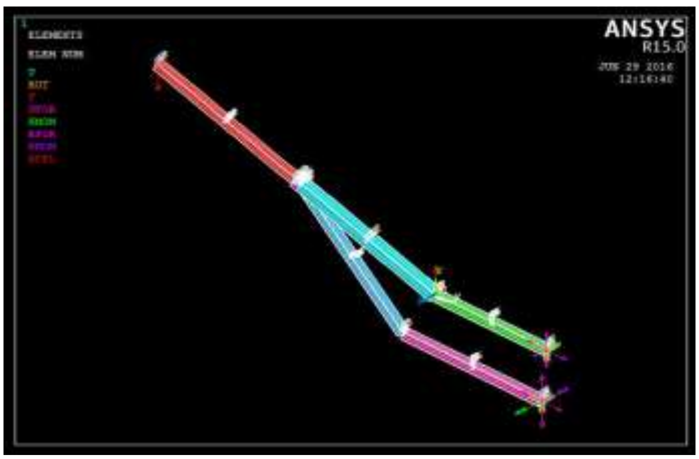
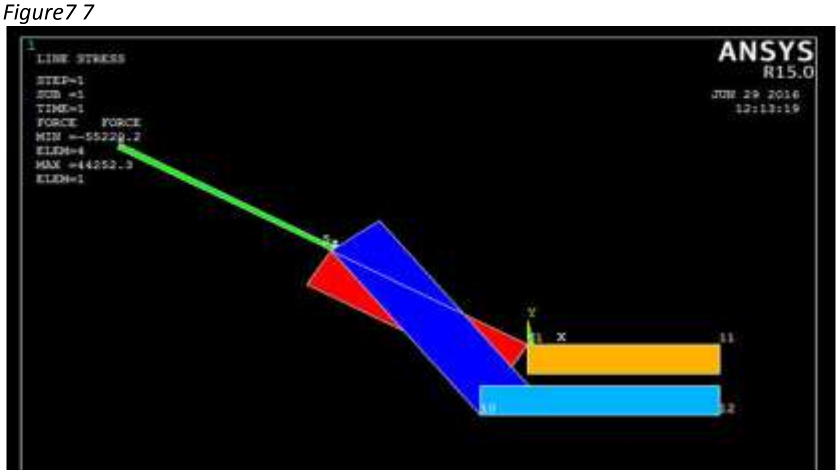


Figure 6

Figure7 7



Computation based on ANSYS is as shown figures 6 and 7. Figure 6 shows the configuration of machine and figure 7 shows force distribution

Forces in KN	Cylinder Force Fbd	Reaction at hinge A
Vector Mechanics	55.20	44.356
Ansys APDL	55.22	44.252
% Error	0	0.23

Table 1

Table 1shows the comparison between vector mechanics and ANSYS results. Error is of 0%. Hence it is concluded that the methodology based vector mechanics approach is valid for the analysis.

Based on the vector mechanics methodology Mat Lab programme is written for all possible combinations of boom position.

Von Mises stress calculation:

For one of the configuration results are obtained from the vector mechanics approach and for the same configuration ANSYS based results are obtained.

Luffing angle θ= 0 degree , slewing angle α=10 , external load P = 10KN weight of

the boom W = 4.285 KN . Section thick ness is 20 mm .

Forces in

Global coordinates	Local coordinates
• F_{ax} = 51.968 KN	F_{ax} = 49.587 KN
• F_{ay} = -10.693 KN	F_{ay} =-10.693 KN
• F_{az} = -9.163 KN	F_{az} =-18.047 KN
• F_{dbx} = -51.968 kN	F_{dbx} =-49.587 KN
• F_{dby} = 24.978 KN	$F_{db\ y}$ =24.978 KN
• F_{dbz} = 51.968 kN	F_{dbz} =18.048 KN

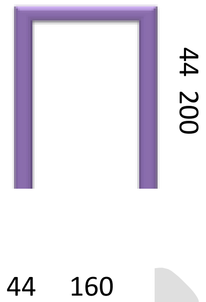
Material used is steel A36, material details are given in the Appendix A, case2.

Section details : Cross section is as shown in figure

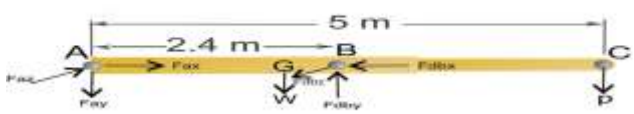
Width = 160 mm

Height = 200 mm

Thickness = 20 mm



Free body diagram for stress calculation is as shown in figure 8.



Shear force and Bending moment diagram are as shown in figure 9

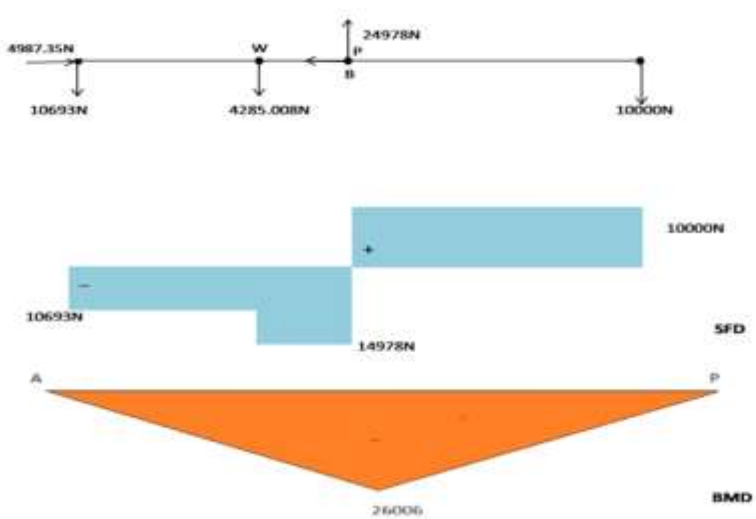


Figure 9

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Figure 10 shows the ANSYS computation results

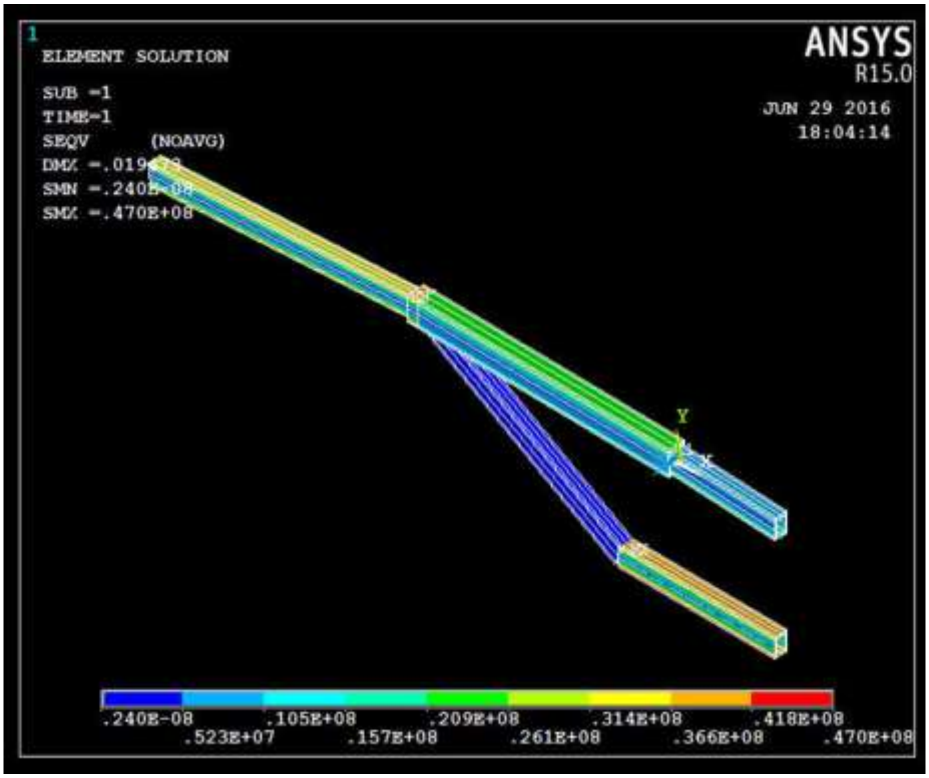

Figure 10

Stress comparison with one of the commercial FEM software ANSYS :

	Von mises stress in Mpa
Vector mechanics	47.71
ANSYS APDL	47

Table 2

Stress comparison with one of the commercial FEM software ANSYS :

	Von mises stress in Mpa
Vector mechanics	47.71
ANSYS APDL	47

Table 2

Table 2 shows the comparison between vector mechanics and ANSYS results. Error is of 1.48%. Hence it is concluded that the methodology based vector mechanics approach is valid for the analysis.

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3 RESULTS

Effect of variables on cylinder force and Von mises stress :

Figure 11 shows the graph of luffing angle in CCW direction v/s cylinder force. As luffing angle increases force on cylinder decreases .

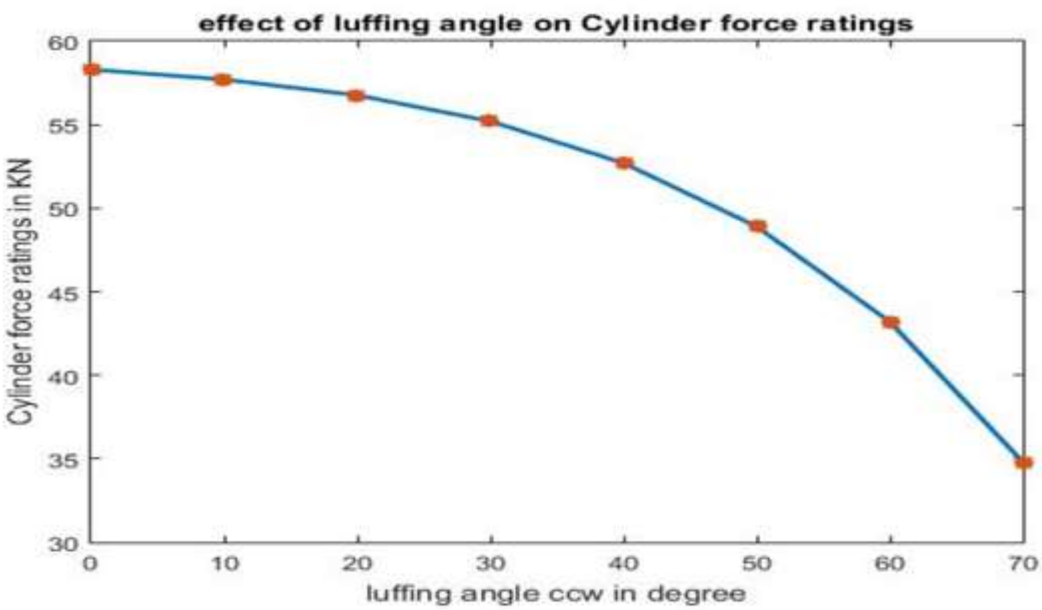

Figure 12 shows the graph of luffing angle in CW direction v/s cylinder force .As luffing angle increases force on cylinder also increases

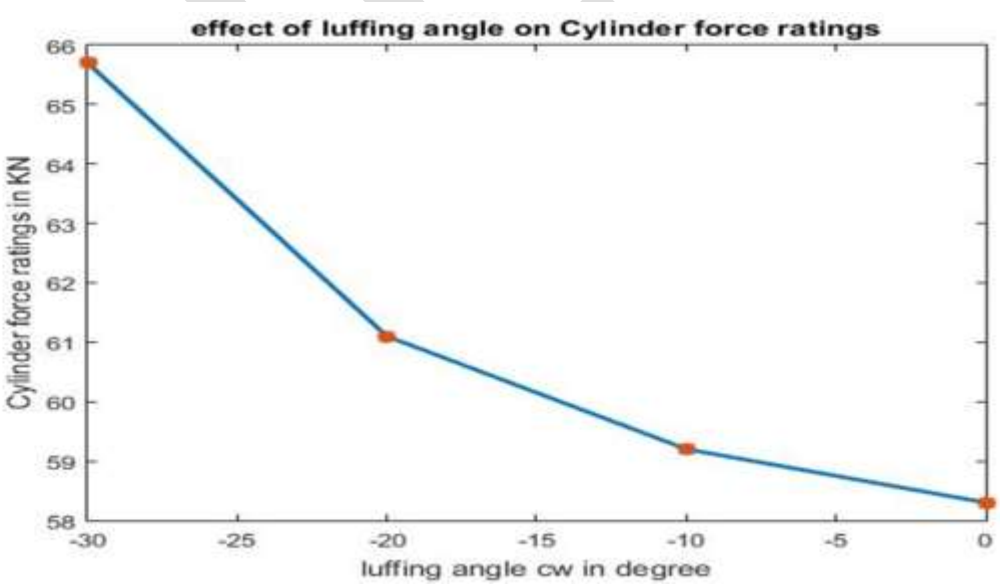

Figure 12

Figure 13 shows the graph of slewing angle v/s cylinder force .As slewing angle increases force on cylinder remains constant

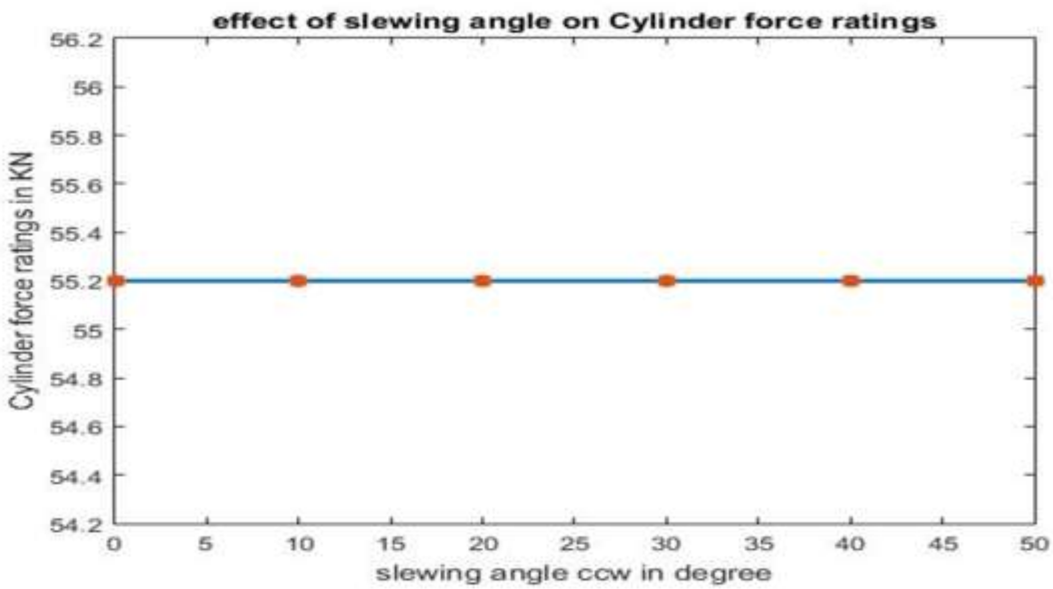

Figure 13

Figure 14 shows the graph of external load v/s cylinder force .As load increases force on cylinder also increases.

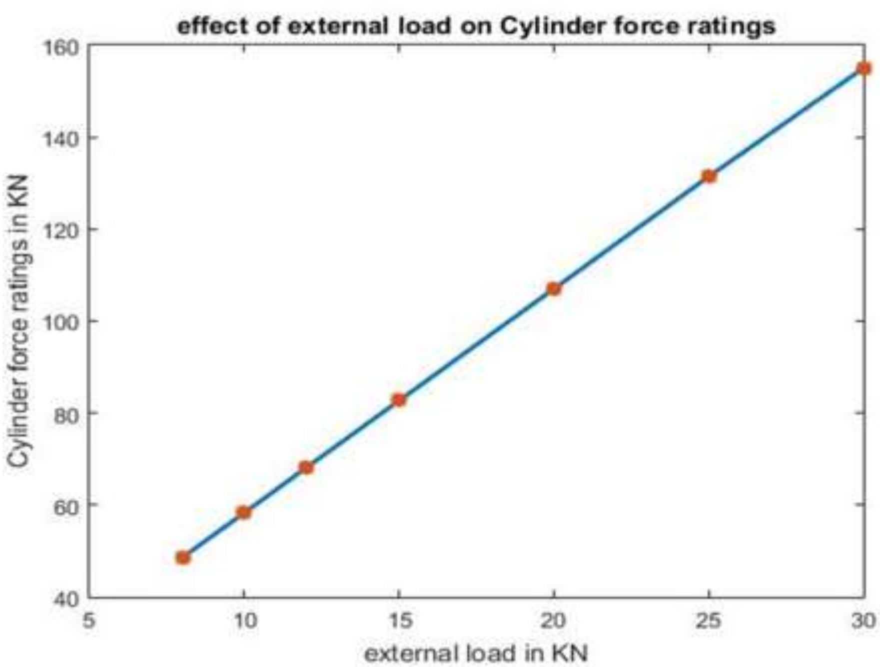

Figure 14

Figure 15 shows the graph of luffing angle v/s Von mises stress. As luffing angle increases ,Von mises stress increases upto 40° ,after that it decreases.

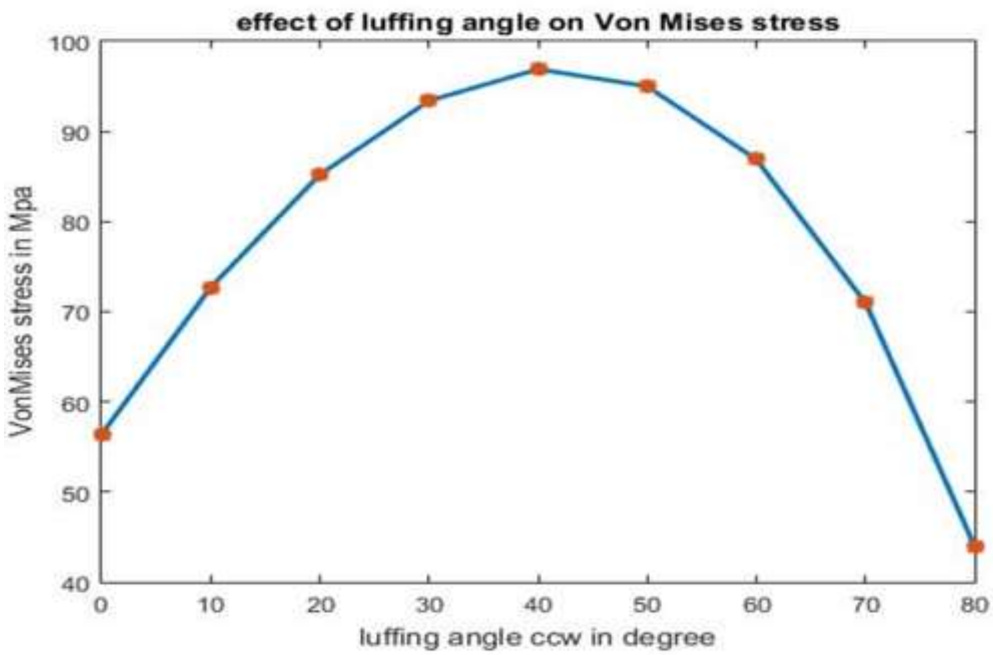

Figure 15

Figure 16 shows the graph of slewing angle v/s Von mises stress. As slewing angle increases ,Von mises stress increases upto 10° ,after that it decreases.

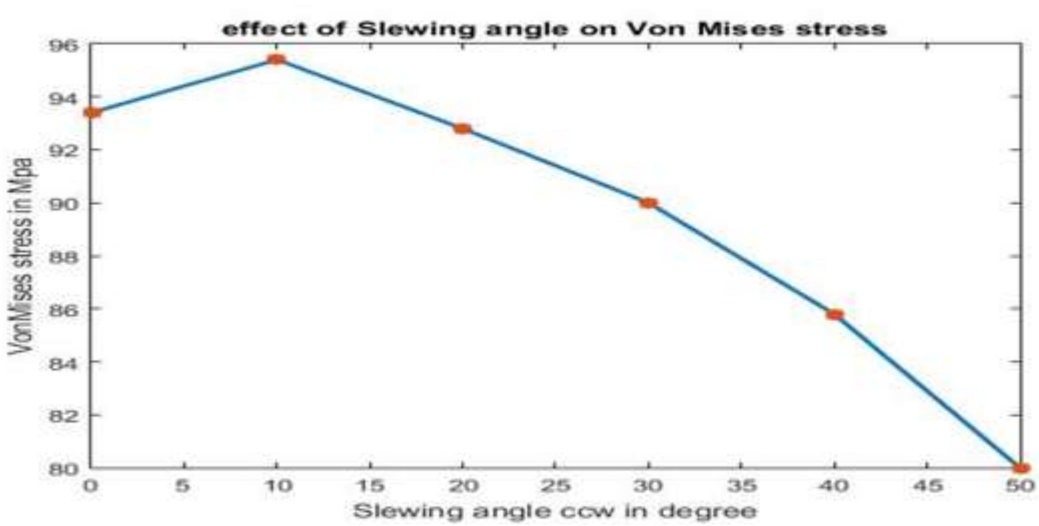

Figure 16

Figure 17 shows the graph of external load v/s Von mises stress. As load increases ,Von mises stress also increases .

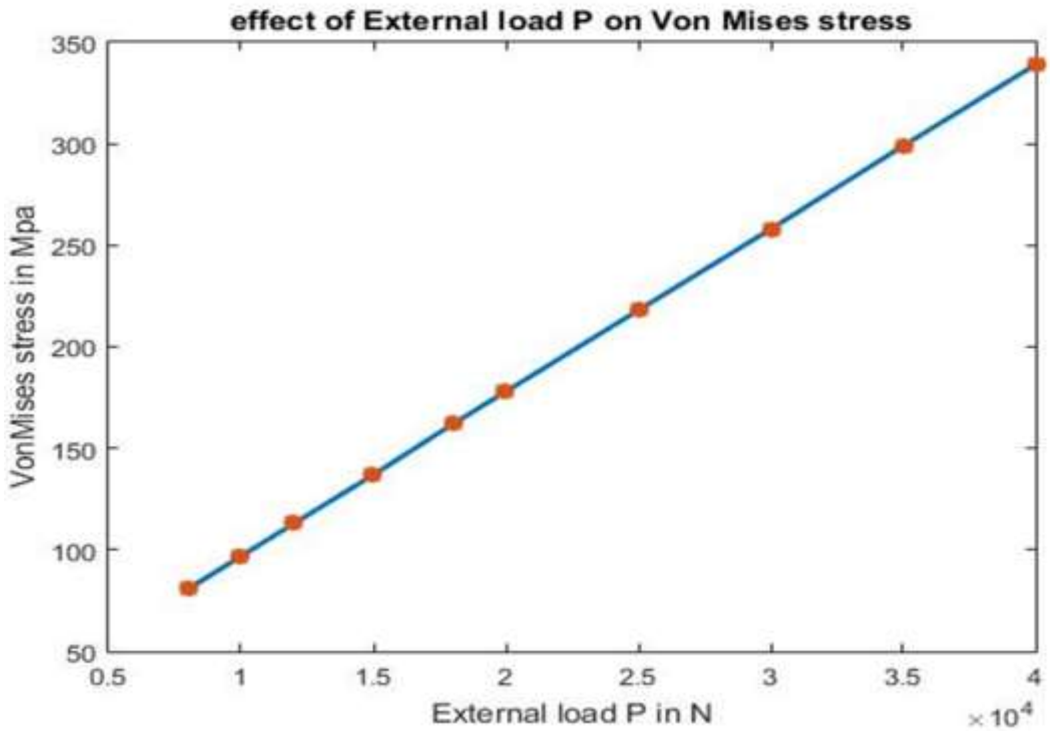

Figure 17

The results are shown for the one of the calculation and configuration of the static problem

4 CONCLUSION

The Vector mechanics approach for the structural analysis and critical design criteria of front end loading machines is an off spring of conventional scalar method. For three dimensional analysis vector method is the best suitable option. From the analysis it is concluded that vector mechanics approach yields accurate results within less time than that of the FEM. However the FEM is the bench mark for the initial development of vector mechanics methodology.

Front end loading machines are critical to analyse because of their complex vehicle integrity. The efforts are made to overcome this complexity in this methodology. Results obtained are useful in the Adaptive Design.

Mat Lab programming which is outcome of the vector mechanics calculation for the analysis helps to reduce the calculation time and we can conclude that both Vector mechanics and Mat lab programming can replace the FEM package for the initial stages of the adaptive design.

Optimization can be increased to higher level by using the exact dimensions and by writing the 3D Mat Lab programming.

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