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Rigid-Body Dynamic Analysis Of A 4-DOF Hydraulic Excavator Attachment Backhoe As A Multibody

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Abstract: An excavator is an off-road vehicle or machine used for several types of construction activities. It has an attachment called a backhoe that is widely used for digging. While digging the earth's massive force works on bucket tips and may bring deformation in it. In this paper an attempt is made to quantify the value of the variables obtained while the all-attached backhoe is considered as a multibody, given in rotation to each joint and simulated in Ansys. The results obtained show that the deformation obtained is small at low rotation and large at high rotation rate. Comparison of the deformation, joint forces and velocity at each set of rotation has been tabulated in x, y and Z directions as well as the overall velocity, total joint force and deformation has also been calculated. This paper provides the base to study and design a multibody system which may undergo deformation so that the end effect may be obtained precisely as required in precision tools and machinery.

Keywords- Design, simulation, deformation.

1. INTRODUCTION

Backhoe loaders are used for a variety of tasks such as construction, demolition and easy transport of building materials. The excavator's backhoe contains hydraulic cylinders, boom, arm, and bucket. Rather pushing the material forward, the backhoe bucket pulls the earth back towards the body of the machine [1]. Due to the working condition of excavator, parts such as bucket, arm, and boom are subjected to high loads. During excavation there is an unknown resistance force that is offered by the earth to the teeth of the bucket. Several studies have been done related to the Design and Performance of the various parts of the excavator [2-6]. In this paper all the attachments are considered as single body and the transformation process obtained when rotation is given to the joints. As the attachment material is flexible and ductile so there must be some deformation due to its own weight and due to the moment of position of center of gravity of each component. The dynamic response of the excavator indicates its effectiveness. To improve the performance of the excavator, an excavator model based on virtual prototype technology is developed just like building a visual prototype.

Fig 1 Backhoe Loader

Simulation process

In a conventional design process, laboratory tests are performed to mimic the visual prototype to test the function of the excavator. Finite element analysis using Ansys, the simulation of virtual prototype for product design has become a major tool. In modern design processes the virtual simulation enables the testing of the performance of the excavator prior to final design and practical application. Virtual prototype technology reduces the cost of a product development cycle and predicts product performance to provide a basis for further product development. The following steps are used for simulation -

Step 1-Building 3-D CAD model.

For this the excavator backhoe model of JCB-ECO expert 3Dx was measured practically on field and with the dimension so obtained, an assembled CAD model was developed in Solidworks. The model was imported in Ansys 19.2 and saved. The simulation is performed in various sets of rotation angles at various joints.

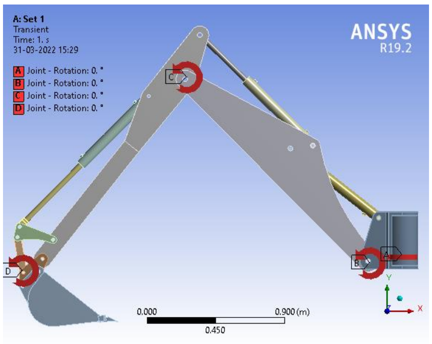

Fig 2 CAD model

Step 2- Adding the property of materials and constraints.

The property of material of the parts are added, according to the actual working condition. The material assumed is structural steel which has ductility and it can be used for both rigid body dynamic analysis and flexible body dynamic analysis. Determined the mass of Bucket-30.181 kg, mass of Arm- 58.914 kg, mass of Boom- 102.06 kg.

Object Name	Geometry
State	Fully Defined
Definition	
Source	E:\Alok Sir Analysis\ak_files\dp0\SYS-15\DM\SYS-15.agdb
Type	DesignModeler
Length Unit	Meters
Display Style	Body Color
Bounding Box	
Length X	2.6433 m
Length Y	1.962 m
Length Z	0.44467 m
Properties	
Volume	5.0007e-002 m³
Mass	392.55 kg

Fig 3 Material Properties

Step 3- The establishment of a rigid body

The assembly as a whole is assumed as a rigid body and for this the stiffness property required is set as rigid.

Object Name	STICK	BUCKET_18 BUCKET 2.29CU. FT.	PIVOT BUCKET LINK	BUCKET LINK_SHORT	2.5X30 X1.25 DA HYD CYL	2.5X30 X1.25 DA HYD CYL inner shaft	BOOM	2.5X20 X1.5 DA HYD CYL	2.5X20 X1.5 DA HYD CYL inner shaft	BOOM TURRET	BOOM TURRET
State	Meshed										
Graphics Properties											
Visible	Yes										
Transparency	1										
Definition											
Suppressed	No										
Stiffness Behavior	Rigid										
Reference Temperature	By Environment										
Material											
Assignment	Structural Steel										

Fig 4 Establishment of Rigid body and meshing.

Step 4- Finite element meshing

The tetrahedral element is selected for meshing and meshing is performed.

Step 5- Simulation Results & Analysis

After the simulation, using the Ansys post-processing module to carry on the simulation result, obtain the motion law of system and the dynamics curve. Finally, its dynamics performance is grasped.

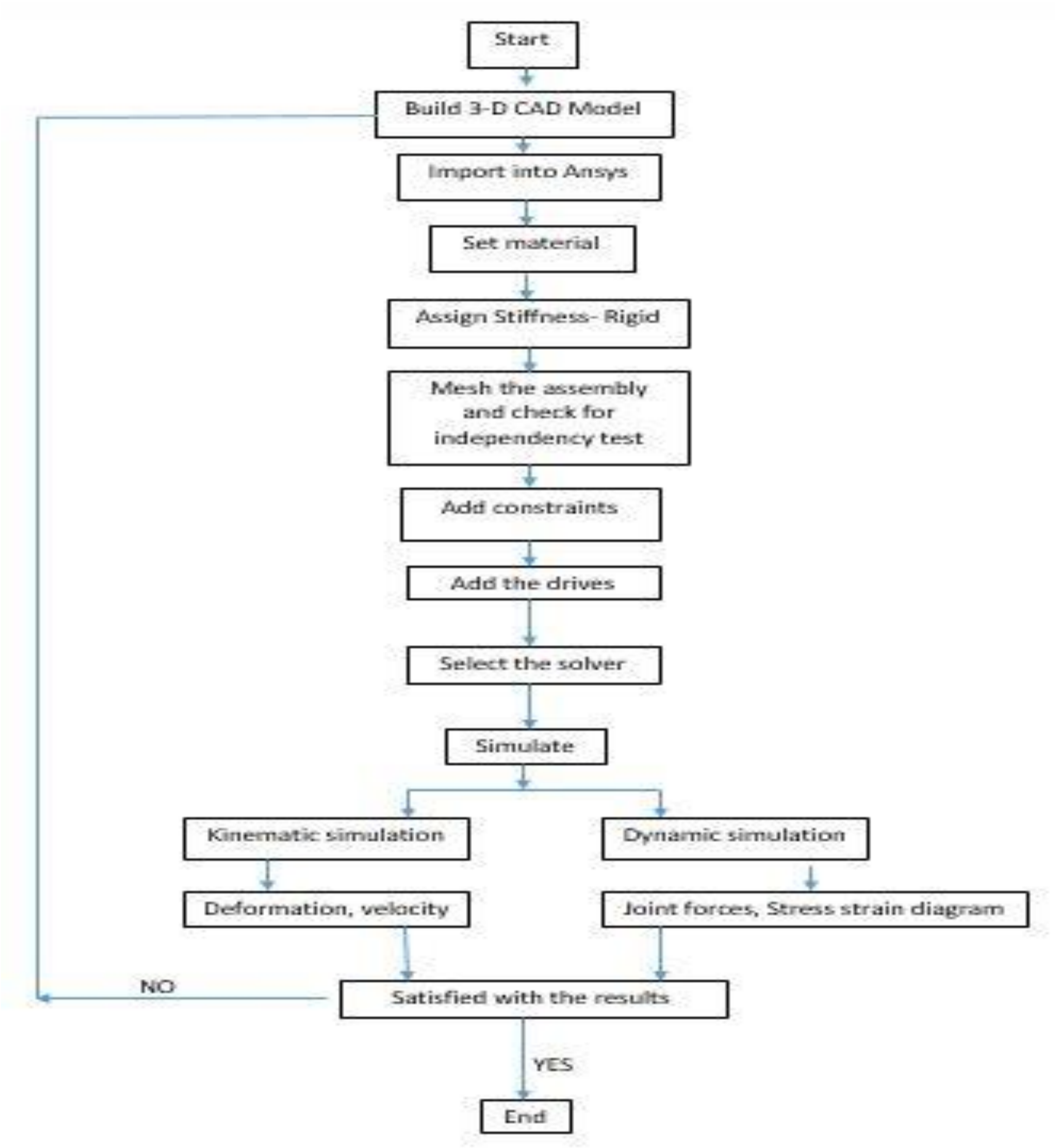

Fig 5 Block Diagram for Simulation Process.

Rigid-body dynamic simulation

(a) Pre-dynamic simulation-

After meshing and independency test of the assembled model the initial position of the parts are assigned and user coordinate system is assigned in each joint.

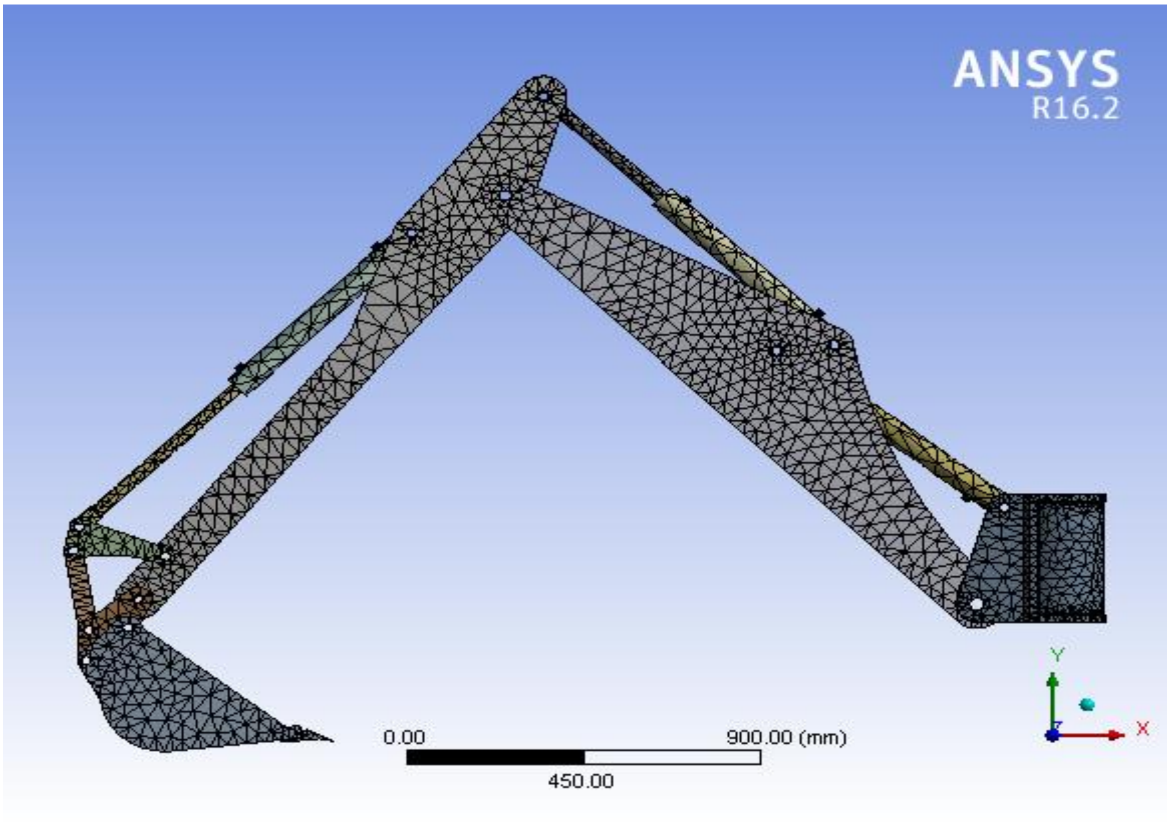

Fig 6 Assembled Model Meshed

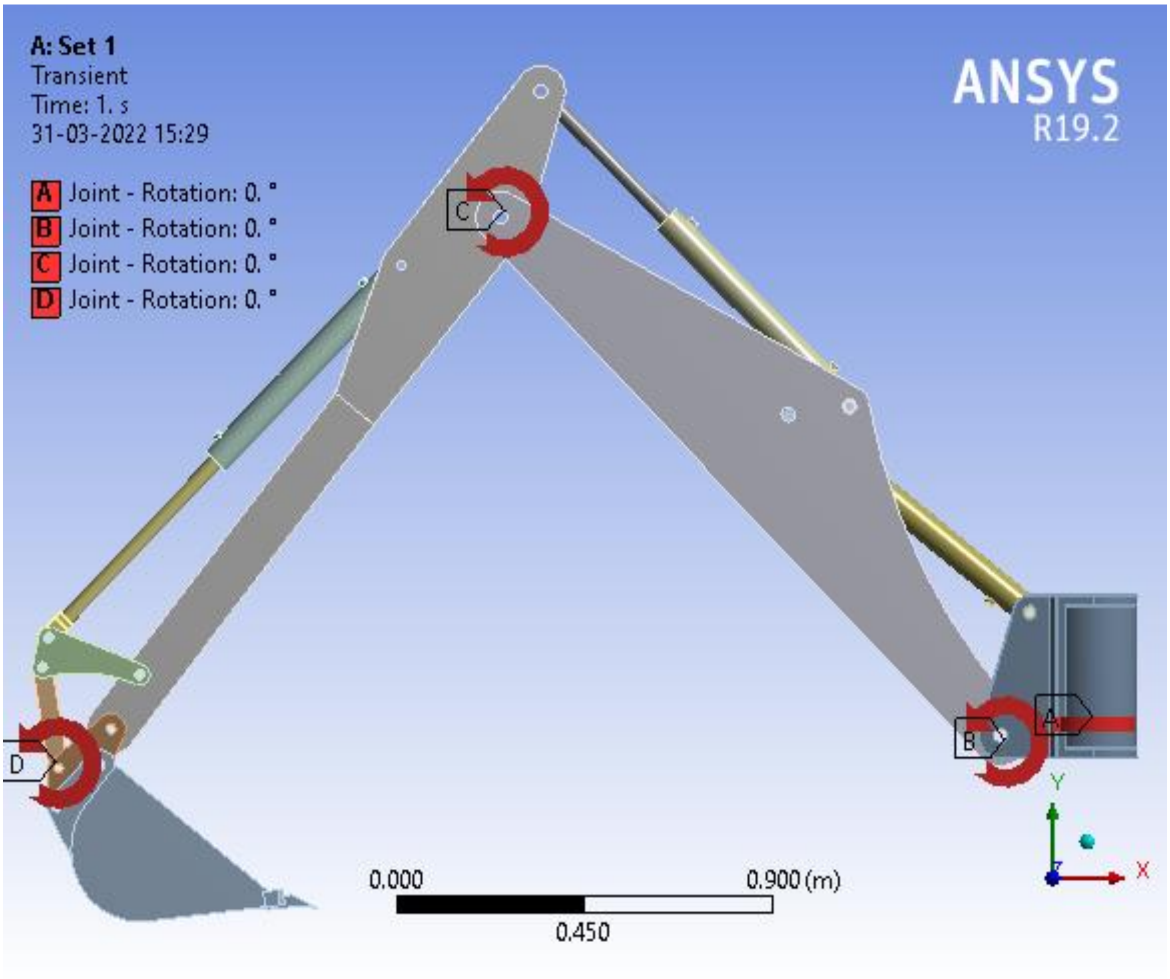

Fig 7 Initial user coordinate set at all 4 joints

(b) Set of Angles-

The simulation is performed at the following 15 sets of angles provided as input for different joints.

Joint A	**Joint B**	**Joint C**	**Joint D**
0	5	5	5
0	10	10	10
0	15	15	15
5	0	5	10
5	5	0	15
5	10	15	0
5	15	10	5
10	0	10	15
10	5	15	10
10	10	0	5
10	15	5	0
15	0	15	5
15	5	10	0
15	10	5	15
15	15	0	10

This paper chooses the simulation time as 25 sec and the step size is 1 sec.

(c) **Results obtained-**

Results for various sets of angles are compared via graphs.

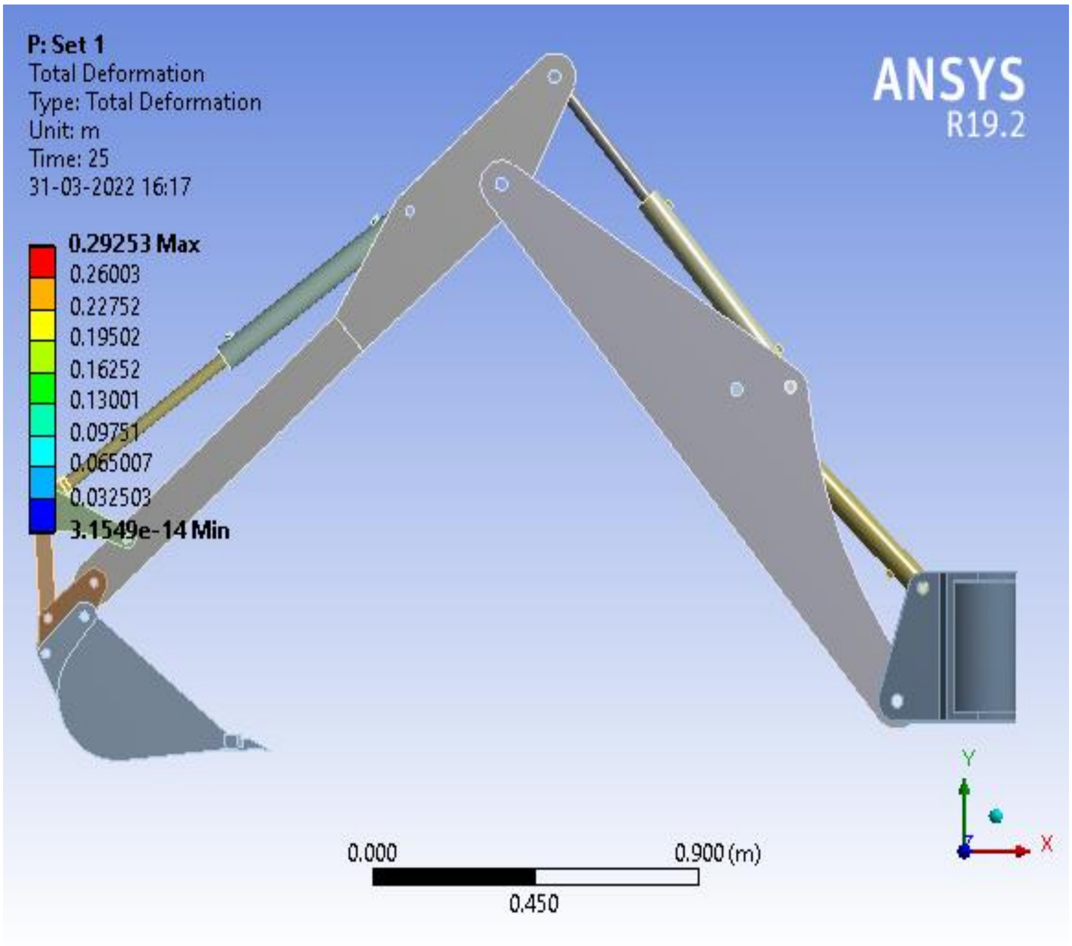

Fig 8 Deformation obtained for set 1.

(i) Results for joint forces-

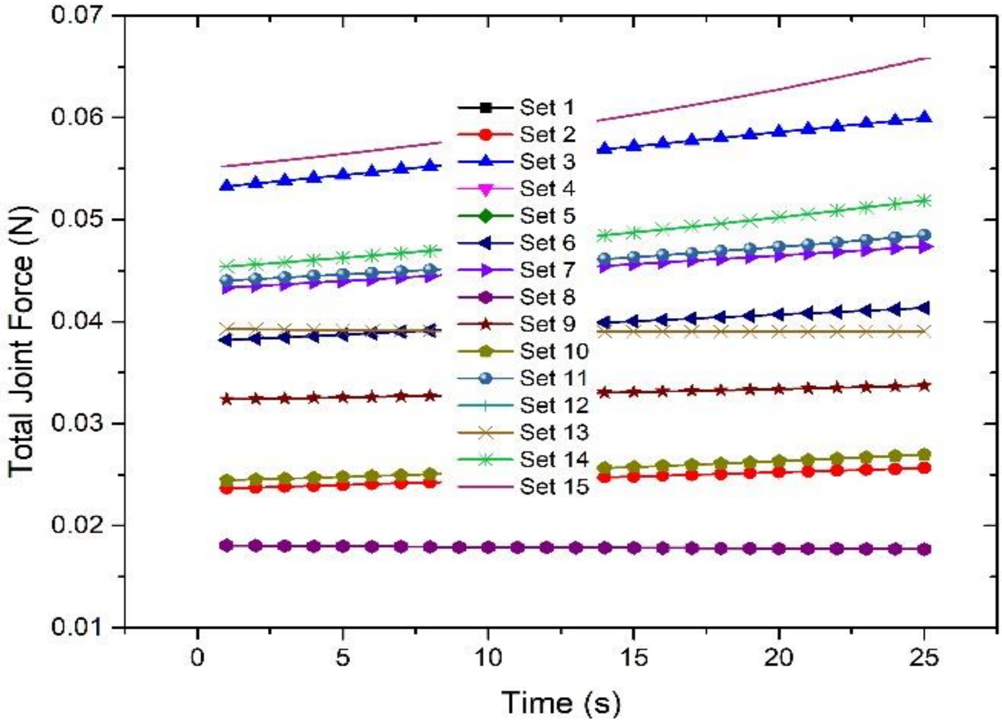

Fig 9 Total joint force

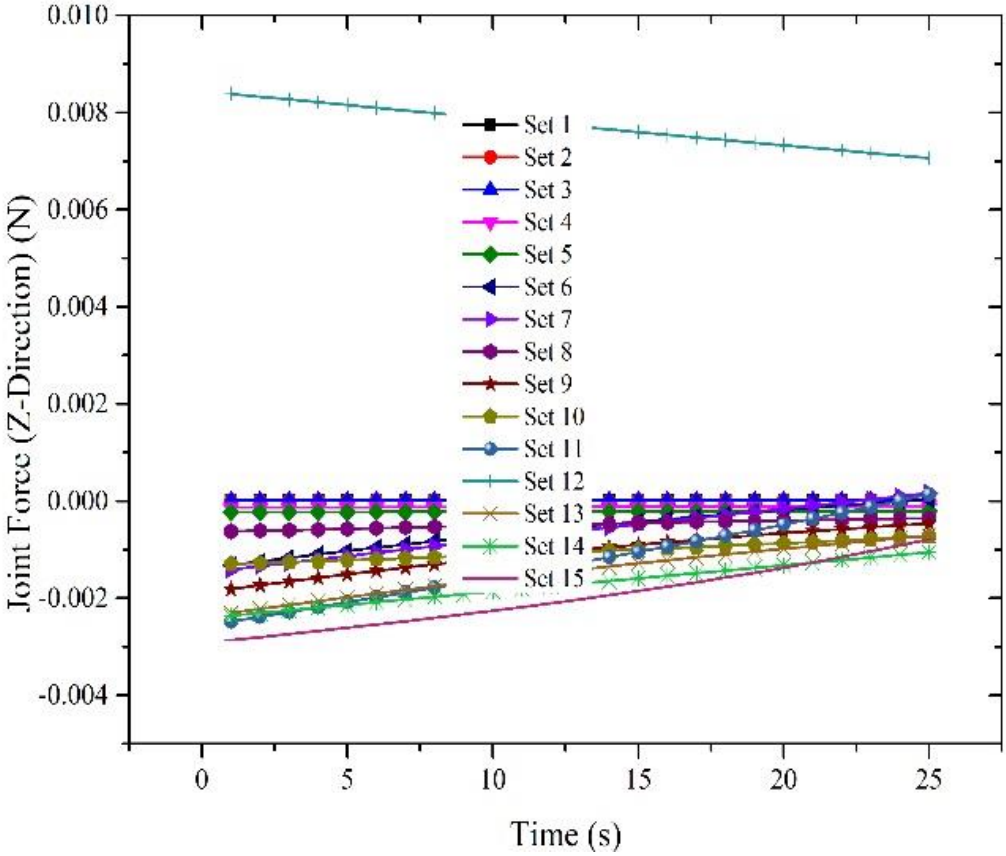

Fig 10 Joint force in Z- direction

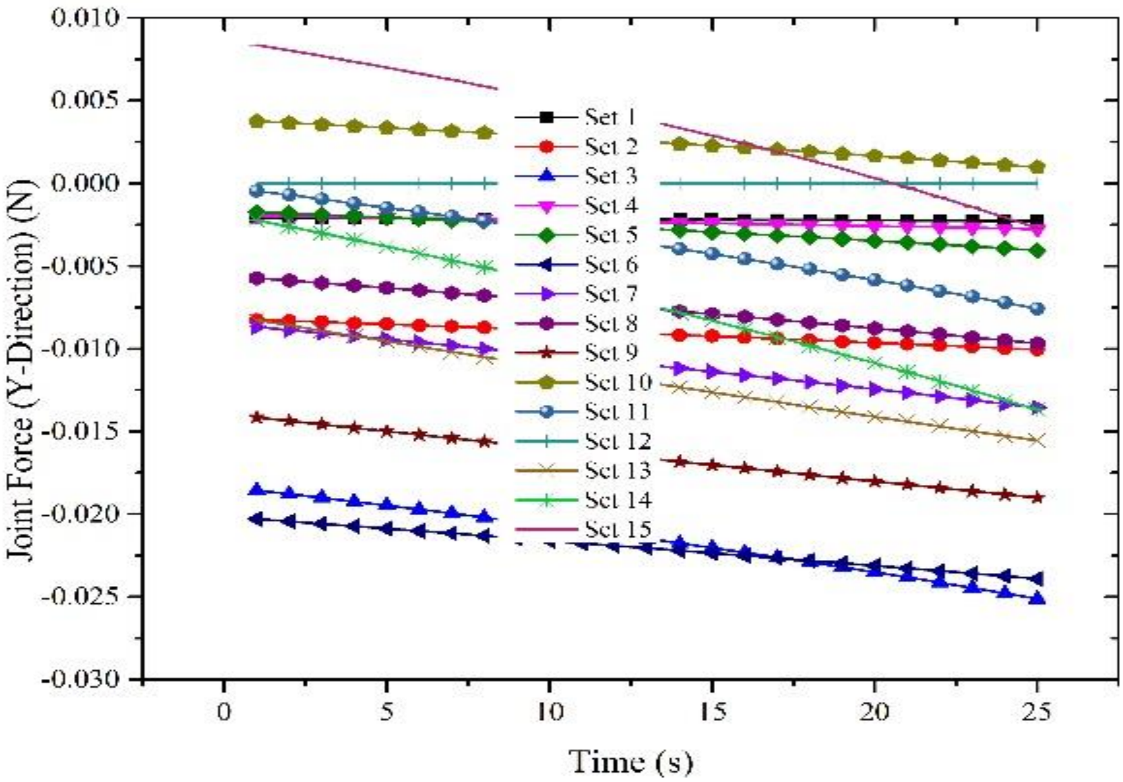

Fig 11 Joint force in Y- direction

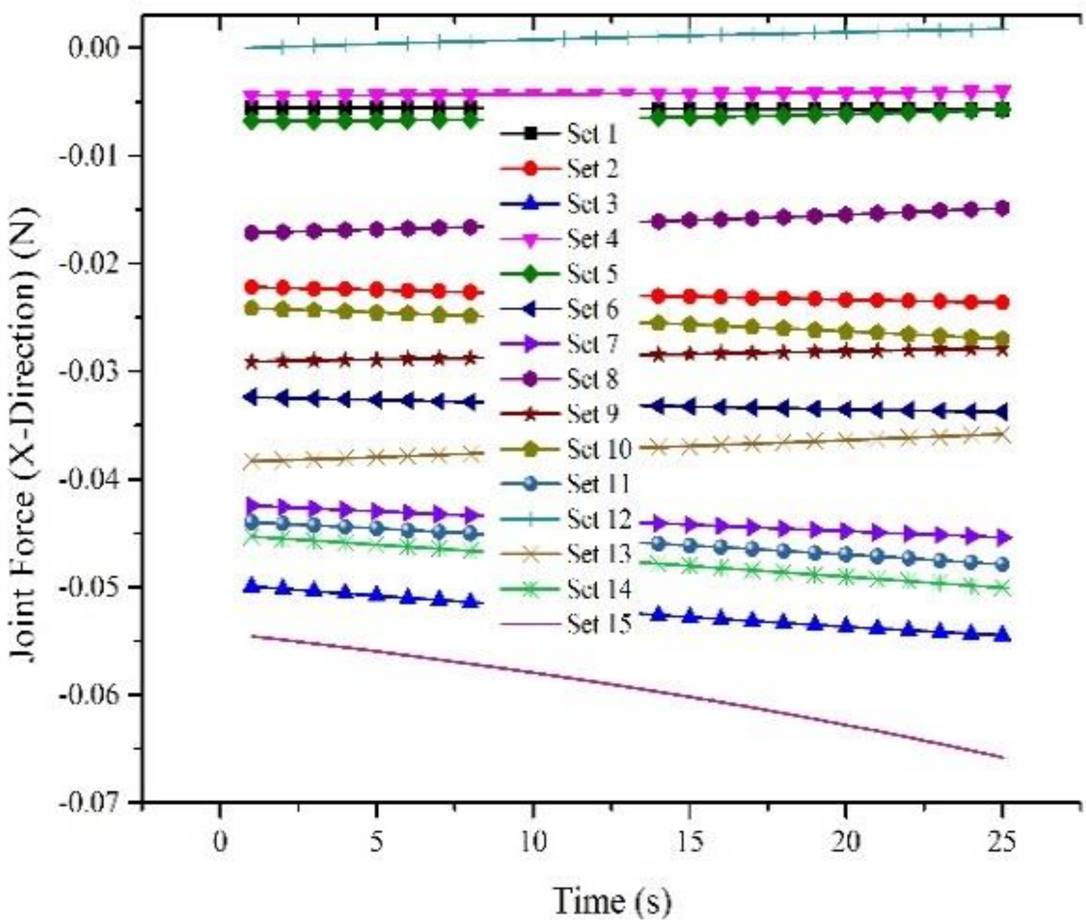

Fig 12 Joint force in X- direction

(ii) Results for Velocity-

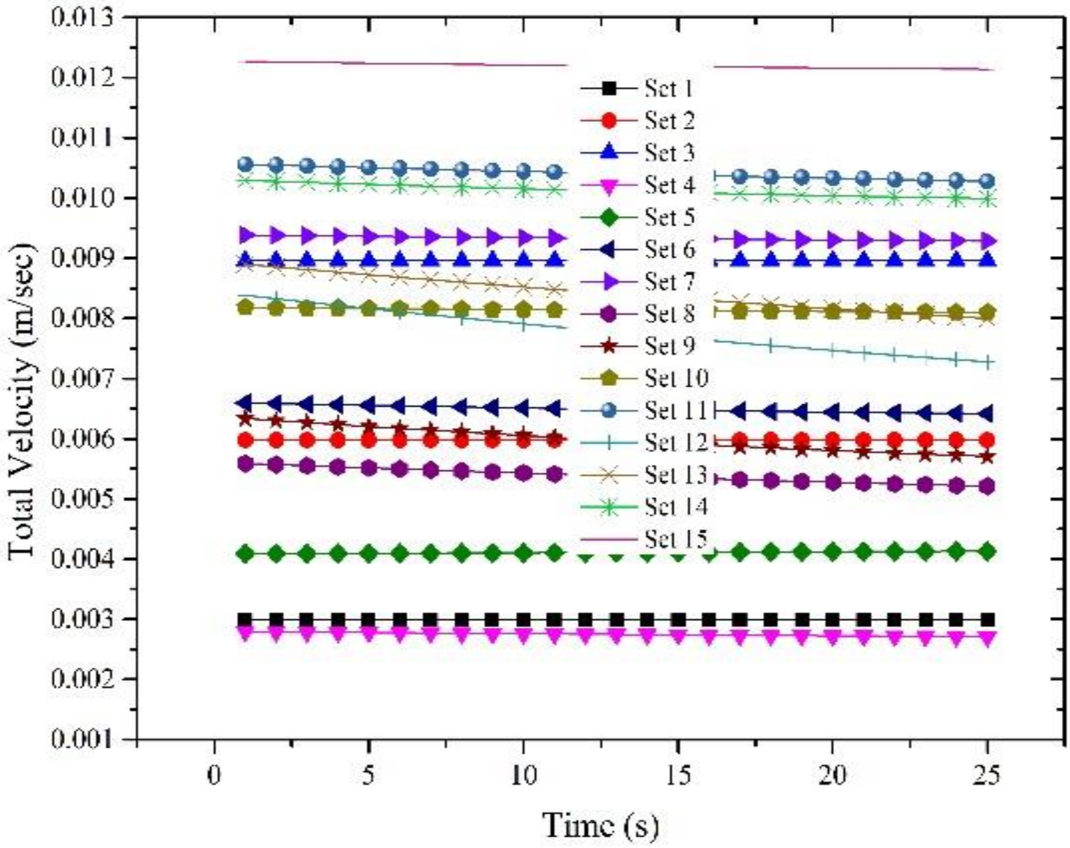

Fig 13 Total velocity

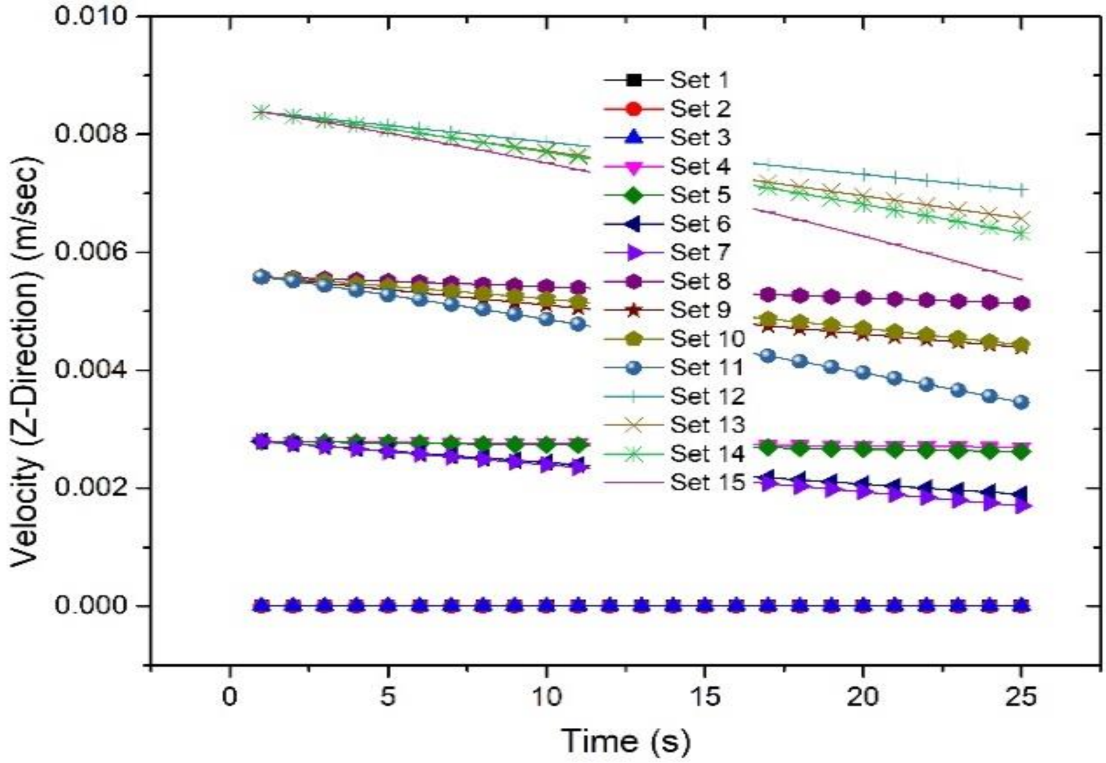

Fig 14 Velocity in Z-direction

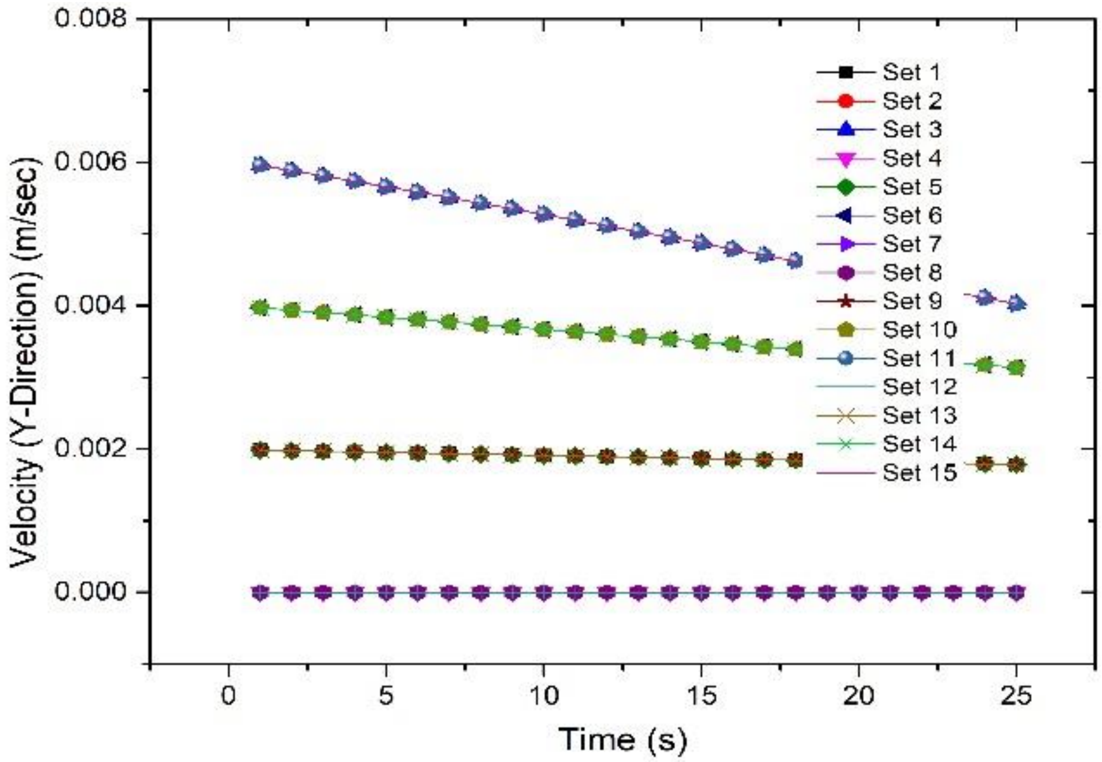

Fig 15 Velocity in Y-direction

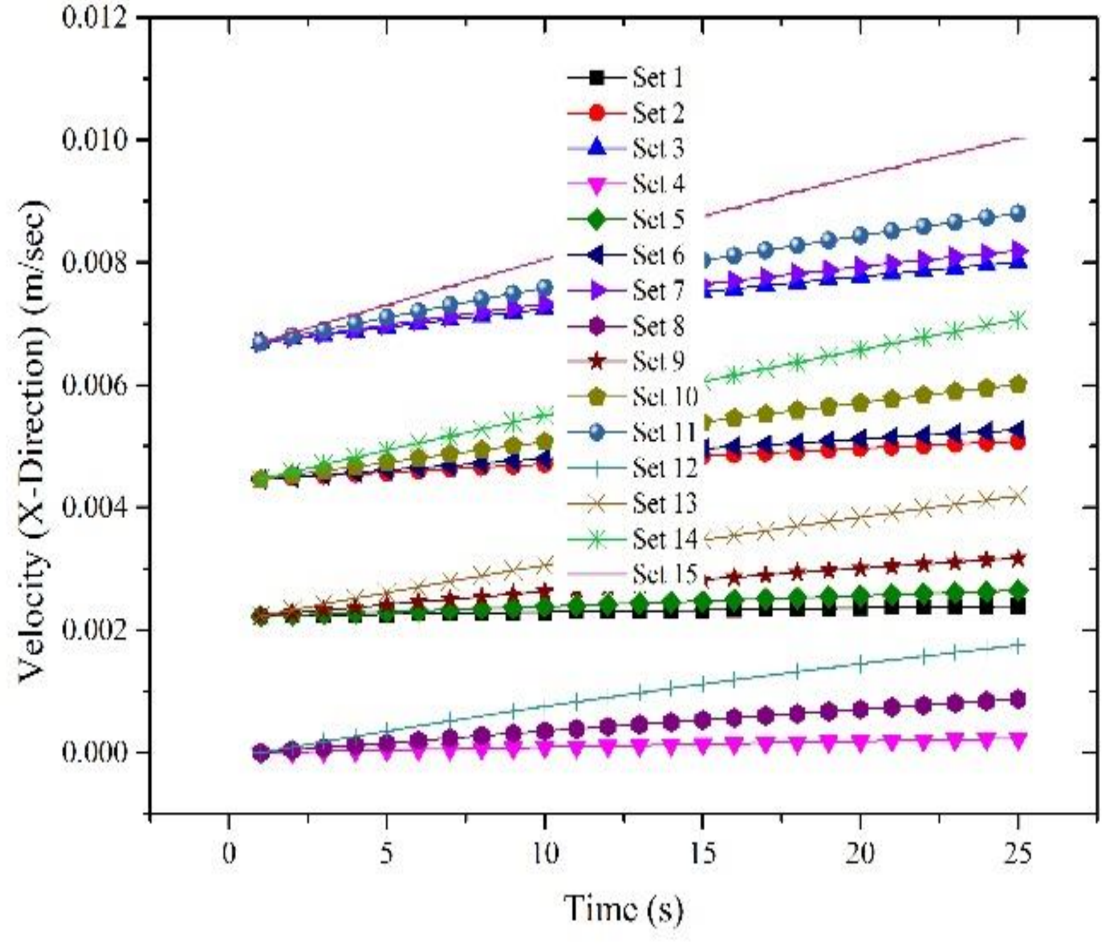

Fig 16 Velocity in X-direction

(iii) Results for deformation-

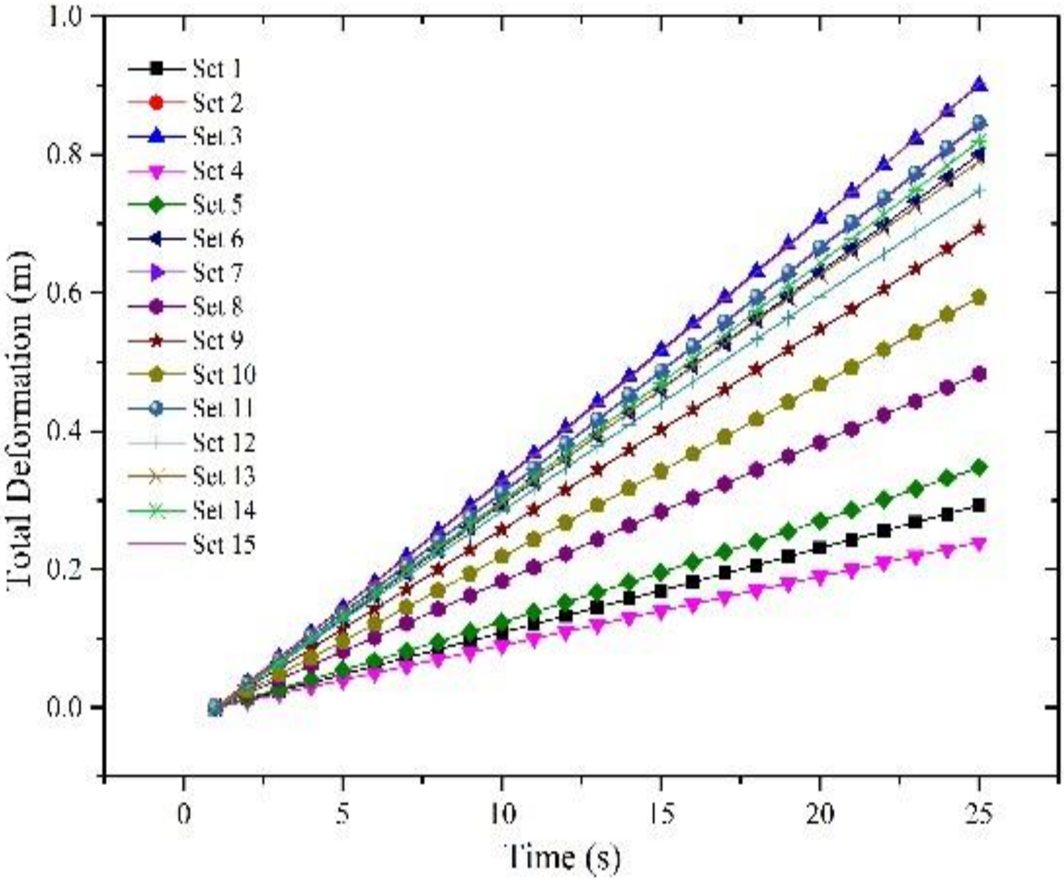

Fig 17 Total Deformation

Conclusion

The paper uses virtual prototyping to verify the necessity of rigid dynamic simulation of excavator. For this-

- First, the model was established in solid works and is assumed as the rigid body. The simulation of the model is carried out on the boom, dipper arm and bucket simultaneously.
- Secondly, the total joint force, total velocity and the total deformation of boom, dipper arm and bucket as a whole are obtained.
- Third, by comparing the results at various sets of angles it is concluded that the total deformation was obtained minimum in set 4 and maximum in set 7.Also the total joint force was obtained minimum in set 8 and maximum in set 15.The velocity obtained was maximum in set 15 and minimum in set4.The
- Minimum and maximum values so obtained by simulation at critical positions where compared with the mathematically calculated values obtained from kinematic equations formulated [7].
- The various outputs can further be obtained considering the dipper arm and boom as a flexible body. Again a comparison can be made to further study the characteristic behavior of the material. After that an overall comparison can be done to find the difference between the two conditions, rigid and flexible, which may predict the behavior of material.

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