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STATIC STRUCTURAL ANALYSIS OF THE BOOM OF THE EXCAVATOR

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ABSTRACT:

In this research work design and simulation of the boom of a backhoe excavator has been carried out. The boom of the back hoe excavator is a key element and is loaded from both sides. The research work includes design or modeling of the boom of back hoe excavator with appropriate shape and dimensions. Then the finite element analysis method is used to do the static structural analysis and transient dynamic analysis of the Boom of the excavator. This analysis was done with the help of commercial Finite Element analysis package ANSYS. The modeling of the boom of the excavator will be done with the help of solid modeling software PRO E.

The results of the finite element analysis will be used to find the stress distribution of the boom and also the critical areas where maximum chances of failure occurs. The factor of safety of the boom will be analyzed at various locations. These results will act as a basis for the shape optimization of the boom, so that the stresses in the critical areas are reduced and the boom element is prevented from the failure.

KEYWORDS:

EXCAVATOR BOOM, FINITE ELEMENT ANALYSIS, ANSYS, PRO-E.

INTRODUCTION

INTRODUCTION OF BACKHOE EXCAVATOR

The construction of highway, digging of trenches, holes, and foundation requires rapid removal of the soil. Typically digging machines such as backhoe loaders or known as backhoe excavators and hydraulic excavators are used to dig the earth for these applications and to load the material into the dump trucks, or trolleys. Backhoe excavators are used primarily to excavate below the natural surface of the ground on which the machine rests. According to Forestry, Earthmoving and Excavator Statistics Program (FEE Statistics Committee, 2010), a backhoe excavator is defined as “A ride-on dual purpose self-propelled wheeled machine for on and off road operation”. One end with loader arms that can support a full width bucket or attachment and the other end incorporating a boom and arm combination capable of swinging half circle for the purpose of digging or attachment manipulation.” In other words, a backhoe excavator is actually three pieces of construction equipment combined into one unit. These three pieces are a tractor, a loader, and a backhoe. The third piece of the equipment a backhoe also known as a backhoe excavator attachment, is the area of research reported in this thesis. A backhoe is the main tool of the backhoe excavator. It consists of a digging bucket on the end of a two part articulated arm.

Backhoe excavator attachment is four degrees of freedom system, because each of the four links (swing link, boom link, arm link and bucket link) are allowed to be rotated with their respective joint axes only. Backhoe consist four different mechanisms each of which can be controlled independently. The first mechanism is for the swing motion of the swing link relative to the fixed or base link, and can be actuated by swing cylinders. The second mechanism is for the rotation of the boom, which is actuated by boom cylinder thus forming an inverted slider-crank mechanism relative to the frame. The third 3 mechanism is for the rotational motion of an arm, which is actuated by arm cylinder, and is also an inverted slider-crank mechanism. The fourth mechanism is for the rotational motion of the bucket. Since a large bucket oscillation is required, the mechanism used is a series combination of a four bar mechanism, and an inverted slider-crank mechanism, which forms a six link mechanism relative to the arm.

Apart from this, the boom assists only in positioning the bucket and the arm for the digging operation; it does not directly contribute in digging operation. On the other hand, the arm and the bucket directly contribute in the digging operation by generating the required digging forces with the help of the hydraulic actuators. The bucket cylinder generates the bucket curl force, and the arm cylinder generates the arm crowd force to excavate the ground. Maximum crowd force is developed when the arm cylinder operates perpendicular to the arm. The ability to break the material is the best at the bottom of the arc because of the geometry of the boom, arm, and bucket and the fact that at that point, the hydraulic cylinders exert the maximum force drawing the arm in and curling the bucket.

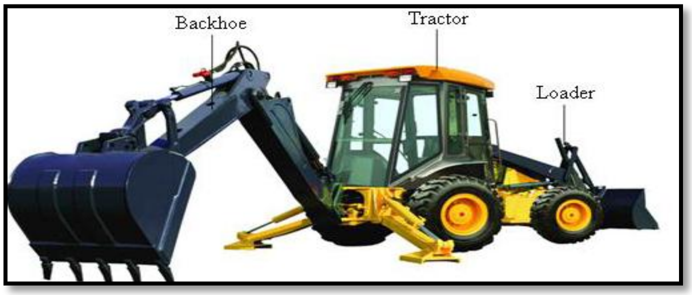


FIG 1: A BACKHOE EXCAVATOR JCB

BACKHOE EXCAVATOR APPLICATIONS IN CONTEXT OF LIGHT DUTY CONSTRUCTION WORK

The compact backhoe excavators can be used for the following applications:

- Construction of highways
- To construct foundations of buildings
- Gardening work
- Forestry work
- To dig holes
- Material handling
- Light duty demolition work
- Urban works
- River dredging

Out of all earthmoving machines (loaders, dozers, hydraulic excavators, backhoe loaders or backhoe excavators, motor graders, haulers, scrapers) or construction machines, hydraulic excavators or backhoe loaders have attained the most attention due to their ease of operation, adaptability to automation, higher excavating capacities by generating higher digging forces to excavate, lesser digging time per cycle thus increasing the productivity of an excavation operation, a greater mobility in compact spaces thus increasing excavating capacities in compact regions as well, widespread availability of the after sales support, etc. This indicates that the backhoe excavators need an attention, as these machines are yet to be developed for the light duty construction work. Moreover in the scenarios of unfriendly environments like the dark, severe weather, hazardous or unhealthy environments, the earthmoving machines could be used effectively, if their operations are controlled automatically. Now a day excavation machines or vehicles are widely used in the earth moving excavation industries, infrastructure development industries, construction industries, and used by civil engineering contractors those are concerned with construction work. These excavation machines are of big size and used for heavy duty construction work, but they are costlier and complex in nature. Sometimes that much heavy duty machines are not required to carry out the digging operation efficiently particularly for light duty construction work and not economical. So there is a scope to develop a mini hydraulic backhoe excavator for light duty construction work. The excavation machines used in construction work are normally operated by human being and their operations controlled manually. In manual digging operation a human operator, plans and executes the bucket motion through the soil with bucket loading and interaction forces between the bucket and soil. During the digging operation, excavator operator cannot know about the terrain condition. As well as in hazardous or toxic environment it is very difficult to operate machine by human operator. Therefore, there is a scope to develop an autonomous excavation machine. The extensive amounts of forces are executed during the digging operation. These forces sometimes adversely affected on the mechanical components of the excavator backhoe and may be damaged during the digging operation. So it is very essential to know the resistive forces developed during the soil-tool interaction. These forces can be predicted by studying the soil-tool interaction models.

Backhoe excavator working under the cyclic motion during the digging operation. The cyclic motion of backhoe link mechanism executes digging forces through actuators. Therefore, it is very important to know the magnitudes of the digging forces and also these forces should be enough to perform the excavation task in soil using bucket teeth as cutting tool. It is necessary that all the parts of backhoe must be robust in design, so that they can withstand against the unknown forces executed during digging operation.

Design of the backhoe mechanism is very crucial because sometime over design of the mechanism will create controlling problems during digging task and not economical. Therefore, structural optimization is required for better controlling of backhoe attachment in autonomous application and for economical operation. Structural weight optimization reduces the initial cost of the backhoe mechanism without affecting its strength. The solution of all above problems can be achieved through understanding and developing the kinematics and dynamics mathematical models of the backhoe mechanism, solid modeling of backhoe attachment, resistive force calculations by applying soil-tool interaction models, digging force calculations, Finite Element Analysis without and with consideration of welding strength and finally by carrying out structural weight optimization of backhoe attachment.

LITERATURE REVIEW

There are a lot of studies in literature and also in Hidromek R&D department about the design of excavator booms as well as other welded structures. Yener [35] parameterized the boom geometry and developed Delphi® based computer program (OptiBOOM) that is competent of automatically creating FEM of the excavator boom by using parametric geometry information and running the Msc. Marc® analysis program to solve the created model. OptiBOOM shortens the FEM creation and analysis time, and assists the designer in improving the structure's weight as well as strength. Yener created more than hundred alternative boom designs and compared with every other in terms of mass as well as stress.The boom design that has been chosen as final design has weighed 3.6 % more than Initial design but maximum the Von Mises stress of the final design has decreased by 21.5% according to the initial design. Usually butt in addition to fillet welds are used in construction of the excavator booms. Fillet welding comprise approximately 80 % of the total welding operation in the excavator boom construction. Mostly welding type in addition to quality determines the life span of excavator boom due to the fatigue.

Fıçıcı [10] modelled 3 dimensional surface cracks in fillet welds to be able to predict the fatigue life of such type of welded connections. Fıçıcı calculated the stress intensity factors about the crack front for the test specimens that are subjected to bending as well as axial loads. Karagoz also modeled three dimensional surface cracks in the fillet welds. J integral values have been calculated for these cracks in T welded joints of the construction machinery. Karagoz used sub modeling technique in the finite element method.

It should be noted that all the welds entail initial flaws in the form of root gaps and may also include other initial flaws potentially depending on the production quality. Stress intensity factor calculation done by Fıçıcı and J integral calculation done by Karagoz are necessary to make successful predictions for the fatigue life of welded structures. One more design study on construction machineries has been completed by Volvo Excavators AB and Alfgam Optimizing. Carlgren et al. has intended to improve fatigue durability of middle boss of the excavator boom. Geometrical modifications are applied to the structure in order to reduce stress intensity factor in weld root gap. They constructed a finite element model FEM as the parent boom model and also a verification model comprising arm and bucket models with lower order shell, bar as well as beam elements.

METHODOLOGY

The methodology of the work will include designing the model in 3D CAD software and then doing the static analysis with the help of ANSYS software. Step wise methodology is listed below.

1) Modelling the boom element with the help of PRO E Software.
2) Converting the PRO E .prt file to IGES file.
3) Importing the IGES model to the ANSYS domain.
4) Applying the loads and Boundary Conditions to the model
5) Finding the solution through simulation on the ANSYS
6) Analysing the results in the ANSYS Postprocessor

RESULTS AND DISCUSSION

Models of Excavator Boom

Different models of the Excavator booms are designed in the Pro E software. The models were designed with the exact dimensions and the best excavator design was selected for analysis on Ansys. The models designed on Pro E are shown below:

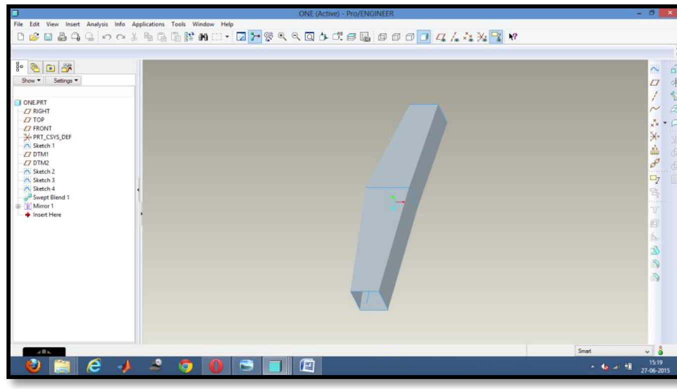


FIGURE 2.MODEL 1(EXCAVATOR BOOM)

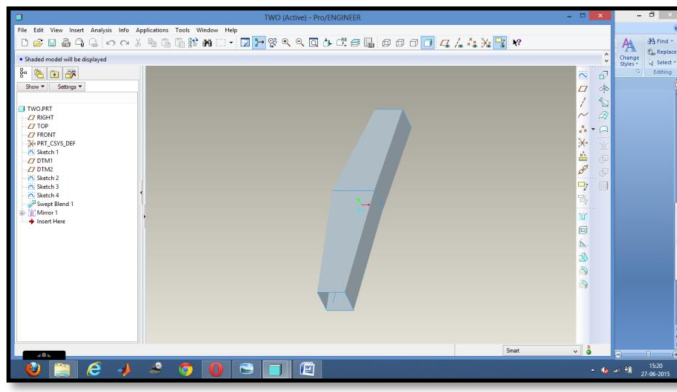


FIGURE 3.MODEL 1(EXCAVATOR BOOM)

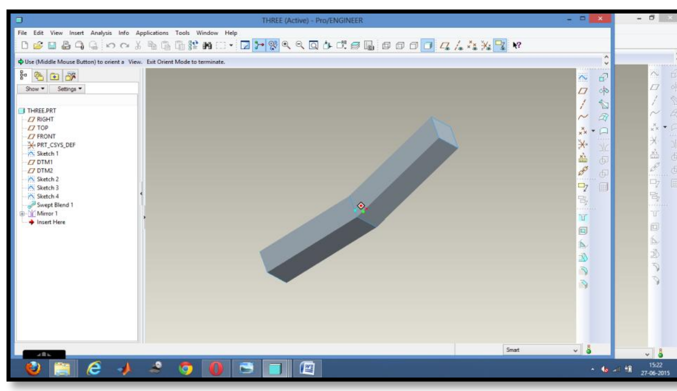


FIGURE 4.MODEL 1(EXCAVATOR BOOM)

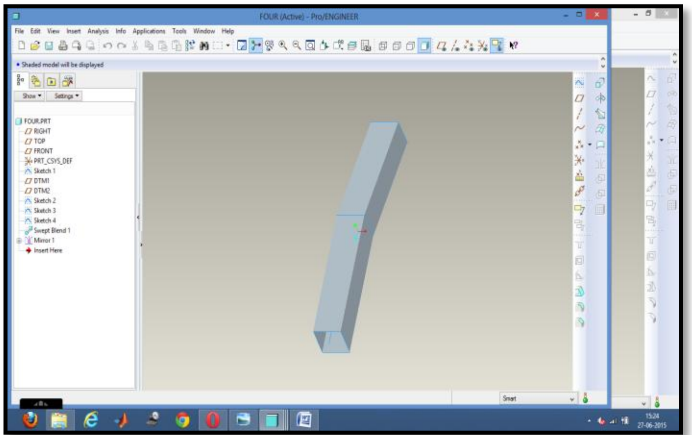


FIGURE 5.MODEL 1(EXCAVATOR BOOM)

STATIC STRUCTURAL ANALYSIS ON ANSYS

A static structural analysis on one of the design was carried on Ansys. The design model from the Pro E was imported in Ansys and the static structural analysis was performed. The following loads boundary conditions were applied to the excavator boom during the analysis:

Load:

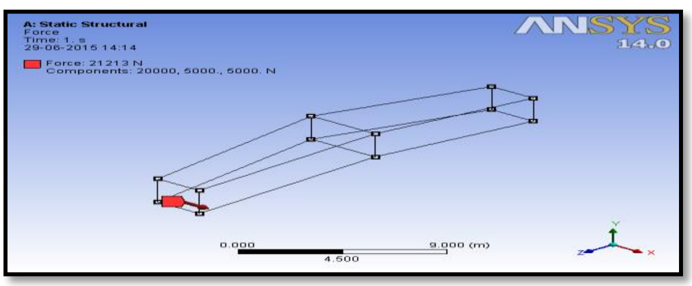
Fx: 20000 N

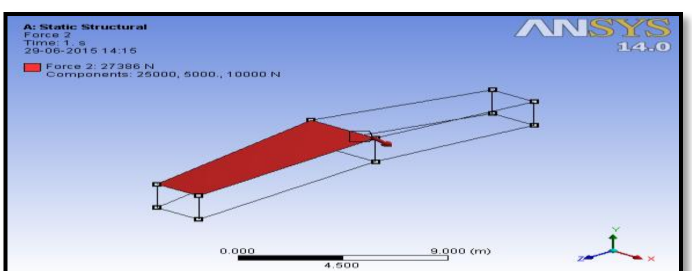
Fy: 5000 N

Fz: 5000 N

Total force F = 21213 N

The loads applied to the boom are shown in the figures below:





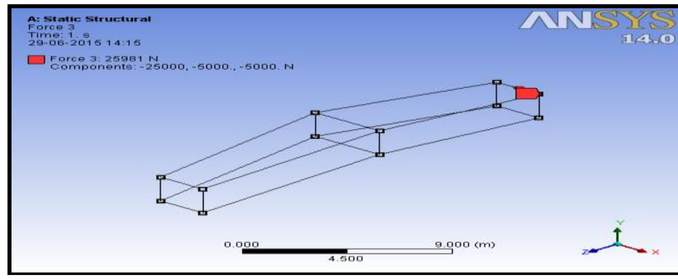


FIGURE 6 APPLIED BOUNDARY CONDITIONS

After the application of load the static structural analysis was carried out on Ansys work bench. The results of the simulation and analysis are shown in the figure below:

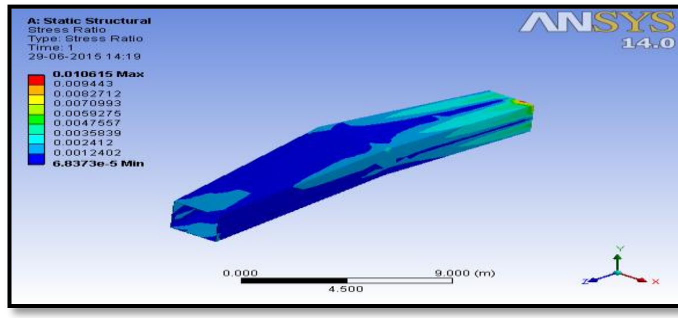


FIGURE 7 STRESS RATIO DISTRIBUTION IN MODEL 1

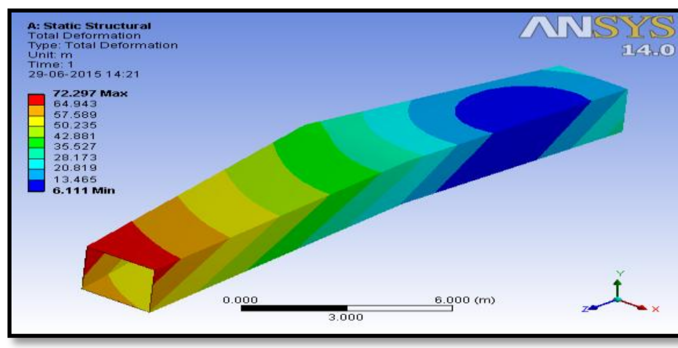


FIGURE 8 TOTAL DEFORMATION IN MODEL 1

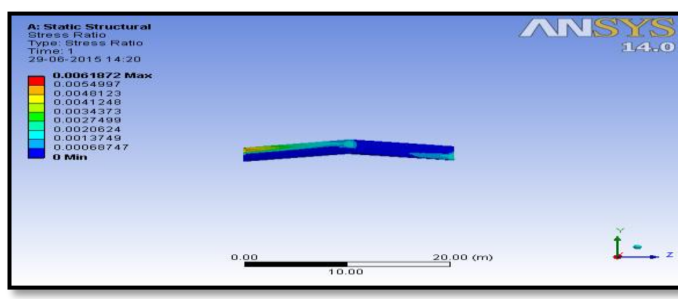


FIGURE 9 STRESS RATIO DISTRIBUTIONS IN MODEL 2

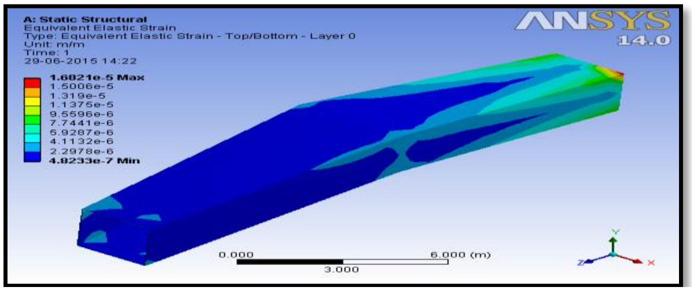


FIGURE 10 EQUIVALENT ELASTIC STRAIN DISTRIBUTIONS IN MODEL 2

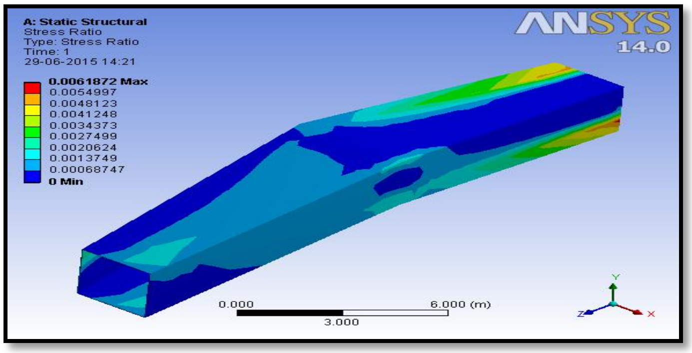


FIGURE 11 STRESS RATIO DISTRIBUTION IN MODEL 3

The figures showing the results are shown. The areas having the maximum stress and deformations are identified. The areas shown in red in the stress and deformation figures are the critical areas. These critical areas are the areas which are subjected to the maximum stress and maximum deformation. Thus the design of the excavator should be modified in such a way that the failure at these critical areas is prevented.

Some of the changes that can be made in the critical areas are increase of the thickness of material at the critical areas. The design at the critical ends can also be modified, like the provision of curve to reduce the stress and deformation at the critical areas.

CONCLUSIONS & FUTURE SCOPE

The static structural analysis gives the stress distribution in the steady state phase. These results can be used to find the critical areas of the boom element to find the critical areas which are more likely to fail.

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Thus these simulations in the CAE software can be used as the basis to change the shape and size of the boom so that a better stress distribution is attained.

The future scope of work includes the transient analysis of the boom of the excavator. Also dynamic analysis of the complete excavator assembly can be considered to determine the optimum performance. The software like ADAMS etc can be used to perform the complete kinematic and dynamic analysis of the back hoe excavator assembly.

REFERENCES

1. Breierova Lucia, Mark Choudhari, An Introduction to Sensitivity Analysis, MIT System Dynamics in Education Project 1996.

2. Carlgren Patrik, Lidström Per, MackAldener Magnus, Hol Dan, Optimization of Welded Component in Excavator Boom, Welded High-Strength Steel Structures 487-502.

3. Chen Ting-Yu, Lin Chia-Yang, Determination of optimum design spaces for topology optimization, Finite Elements in Analysis and Design 36 (2000) 1-16.

4. Das R., Jones R.,Peng, D., Optimisation of damage tolerant structures using a 3D biological algorithm, Engineering Failure Analysis 13 (2006) 362-379.

5. Das R.,Jones R., Chandra S., Damage tolerance based shape design of a stringer cutout using evolutionary structural optimisation, Engineering Failure Analysis 14 (2006) 118-137.

6. Das R.,Jones R., Design of structures for optimal static strength using ESO, Engineering Failure Analysis 12 (2005) 61-80.

7. David E. Goldberg, Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley Publishing Company Inc., USA, 1989.

8. Eriksson Asa, Lignell Anna-Maria, Olsson Claes, Hans Spennare, Weld evaluation using FEM, Indutrilitteratur, Stockholm, 2003.

9. Eriksson Asa, Lignell Anna-Maria, Olsson Claes, Hans Spennare, Weld evaluation using FEM, Indutrilitteratur, Stockholm, 2003.

10. Ficici F., "Three Dimensional Fracture Analysis of Fillet Welds", Ms. Thesis Submitted to Middle East Technical University, Turkey, 2007.

11. Glover Fred, Tabu Search Fundamentals and Uses, US West Chair in Systems Science 1995.

12. Haftka T. Raphael, Gürdal Zafer, Elements of Structural Optimization, Kluwer Academic Publishers, The Netherlands, 1991.

13. Hardee Edwin, Chang Kuang-Hua, Tu Jian, Choi Kyung K., Grindeanu Iulian, Yu Xiaoming, A CAD-based design parameterization for shape optimization of elastic solids, Advances in

Engineering Software 30 (1999) 185-199.

14. Haslinger J., Makinen R.A.E, Introduction to Shape Optimization, SIAM, Society for Industrial and Applied Mathematics, Philadelphia, 2003.

15. Hobbacher A.,Fatigue design of welded joints and components: Recommendations of IIW Joint Working Group XIII – XV, Abington, Cambridge, 1996.

16. Jasbir S. Arora, Introduction to Optimum Design, McGraw Hill Book Co., Singapore, 1989.

17. Jones R., Chaperon P., Heller M., Structural optimisation with fracture strength constraints, Engineering Fracture Mechanics 69 (2002) 1403-1423

18. Karaboğa, Genetic Algorithms in Search, Optimization, and Machine Learning, Addison-Wesley Publishing Company Inc., USA, 1989.

19. Karagoz T., "A Finite Elements Based Approach for Fracture Analysis of Welded Joints in Construction Machinery", Ms. Thesis Submitted to Middle East Technical University, Turkey, 2007.

20. Mehta Gaurav K, "Design and Development of an Excavator Attachment" M. tech Dissertation Thesis, Nirma University, Institute of Technology, Ahmedabad, May 2008, pp. 1.

21. Bhaveshkumar P. Patel, Dr. J. M. Prajapati, "Soil-Tool Interaction as a Review for Digging Operation of Mini Hydraulic Excavator", International Journal of Engineering Science and Technology, Vol.3 No. 2, February 2011, 894-901.

22. Bhargav J Gadhvi, B. P. Patel and P. M. Patel, "Development of a Controller for Mini Hydraulic Excavator as a Review", Proceeding of National Conference on Recent Advances in Manufacturing, SVNIT, Surat, 19th - 21st July, 2010, pp. 198-203.

23. Mehmet Yener, "Design of a Computer Interface for Automatic Finite Element Analysis of an Excavator Boom", M.S. Thesis, The Graduate School of natural and Applied Sciences of Middle East Technical University, May 2005, pp. 1-4, 68-69.

24. Nareshkumar N. Oza, "Finite Element Analysis and Optimization of an Earthmoving Equipment Attachment – Backhoe", M. tech Dissertation Thesis, Nirma University, Institute of Technology, Ahmedabad, May 2006, pp. 31-68.

25. MA Bromfield and WT Evans, "Computer modelling of microexcavator", Computer Aided Design, Butterworth & Co (Publishers) Ltd., Vol. 20, No. 9, November 1988, pp. 549-554.

26. Ram Vadhe and Vrajesh Dave, " Multi-Body Simulation of Earthmoving Equipment using Motionview/Motionsolve", Driving Innovations with Enterprise Simulation, L & T e-engineering Solutions, 1993, pp. 1-5.

27. Jun-Yong Park, Heui-Won Kim and Wan-Suk Yoo, "Matching of Flexible Multibody Dynamic Simulation and Experiment of a Hydraulic Excavator", Proceedings of ACMD, 2004, pp. 459-463.

28. Yefei Li, Xianghong Xu and Qinying Qiu, "FEM-Based Structure Optimization with Grid-Enabled Analysis Environment", Proceedings of the 6th World Congress on Intelligent Control and Automation, IEEE, Dalian, China June 21 - 23, 2006, pp. 6915-6919.

29. Tadeusz Smolnicki, Damian Derlukiewicz, and Mariusz Stańco,c "Evaluation of load distribution in the superstructure rotation joint of single-bucket caterpillar excavators", Automation in Construction, Elsevier, 2008, pp. 218-223.

30. Luigi Solazzi, "Design of aluminium boom and arm for an excavator", Journal of Terramechanics, Elsevier, Vol. 47, 2010, pp. 201–207.