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Review Article

FINITE ELEMENT ANALYSIS OF COMPONENTS OF EXCAVATOR ARM—A REVIEW

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Excavators are intended for excavating rocks and soils. It consists of four link members: the bucket, the stick, the boom and the revolving super structure (upper carriage). The excavator mechanism must work reliably under unpredictable working conditions. Thus it is very much necessary for the designers to provide not only a equipment of maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. The two important factors considered during designing an excavator arm are productivity and fuel consumption. Also the bucket volume is increased to compensate for the loss in production due to the reduction in digging force. Increased in bucket volume will also increase the amount material to be fed in the bucket. The present paper is review of various analysis done on components of excavator arm and there are various forces affects on components of excavator arm. This paper will be helpful for those who are working in the field of civil engineering.

Keywords: Excavators, Excavating, Digging force

INTRODUCTION

An excavator is heavy equipment consisting of an articulated arm (backhoe), bucket and cab mounted on a pivot (a rotating platform, like a Lazy Susan) a top and undercarriage with tracks or wheels. Their design is a natural progression from the steam shovel. Excavators are intended for excavating rocks and soils. Excavators may have a mechanical or hydraulic drive. Hydraulic excavators are the most important group of excavators. Today hydraulic excavators are widely used in construction, mining, excavation, and forestry applications (Bhaveshkumar, 2011).

Excavator digs, elevates, swings and dumps material by the action of its mechanism, which consists of boom, arm, bucket and hydraulic cylinders. Bucket is used for trenching, in the placement of pipe and other under-ground utilities, digging basements or water retention ponds, maintaining slopes and mass excavation. Due to severe working

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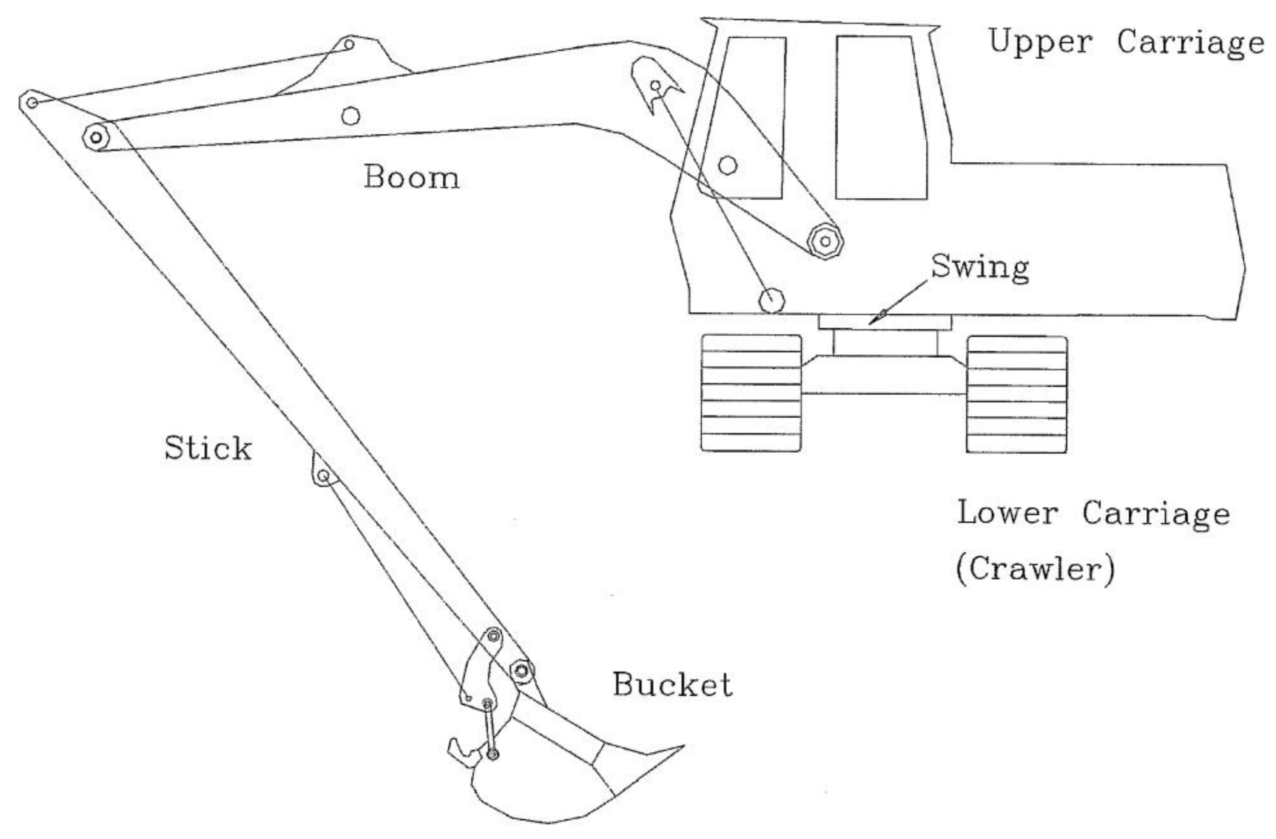
Figure 1: A Typical Hydraulic Backhoe Excavator



conditions, excavator parts are subject to corrosive effects and high loads.

REVIEW OF WORK CARRIED OUT

Jakub Gottvald (2012) evaluated measuring of vibrations on a Bucket Wheel Excavator (BWE) during mining process. They have studied the dynamic behavior of buckets during working under mines. The main aim of this study was on vibration caused and its effect on the arm assembly of the excavator. Natural frequencies and shapes are very significant characteristic of dynamical behavior of structures. Their determination is mostly the first step in solving of various dynamical problems. Knowledge of natural frequencies and shapes gives us the possibility to assume how the structure will be sensitive to dynamical loads. Calculations of dynamical characteristics are very significant part in designing of structures in which various loadings are of utmost priority (Jakub Gottvald, 2011 and Jakub Gottvald, 2012).

Bhaveshkumar P Patel done a tremendous study on kinematics of hydraulic excavator's backhoe attachment. They have formulated a angle arrangement for safety working of a excavator arm by using FEM approach. Also they have done soil-tool interaction study for digging operation of mini hydraulic excavator. Excavators are used primarily to excavate below the natural surface of the ground on which the machine rests and load it into trucks or tractor. Due to severe working conditions, excavator parts are subjected to high loads. The excavator mechanism must work reliably under unpredictable working conditions. Thus it is very much necessary for the designers to provide not only a equipment of maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. It can be concluded that, force analysis and strength analysis is an important step in the design of excavator parts. Finite Element Analysis (FEA) is the most powerful technique in strength calculations of the structures working under known load and boundary conditions (Bhaveshkumar, 2011a and 2011b; and Bhaveshkumar and Prajapati, 2011 and 2012).

Yang Cheng *et al.* (2012) studied the hydraulic excavator from the bodies of the boom, stick institutions, shovel mechanism composed of three parts, and construction machinery is a multi-degree of freedom. Work carried out in this paper mainly focusing on the Bionic Study of Hydraulic Excavator Attachment.

Juber Hussain Qureshi and Manish Sagar (2012) provides the platform to understand the Modeling and FEA of Boom of Backhoe Loader, which was already carried out by other researchers for their related applications and it can be helpful for the development of boom of backhoe loader.

Dongmok Kim *et al.* (2009) prepared the operating algorithm has and verified it in many test cases. They have used CATIA Manikin extension to study the human behavior and the stresses induced in human parts too while operating the excavator arm. They have also prepared a control system for the safety measures. Prior to testing, the algorithms have been verified using the visual simulator.

Rahul Mishra and Vaibhav Dewangan (2013) calculated the capacity of bucket according to SAEJ296. The bucket specification is the most superior when

Figure 2: Digging Force

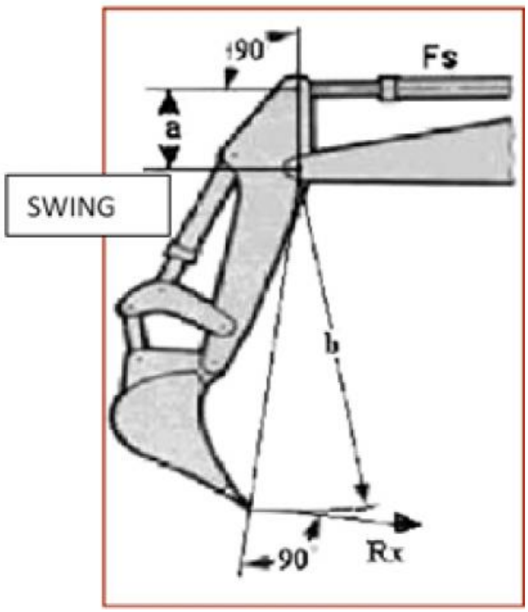
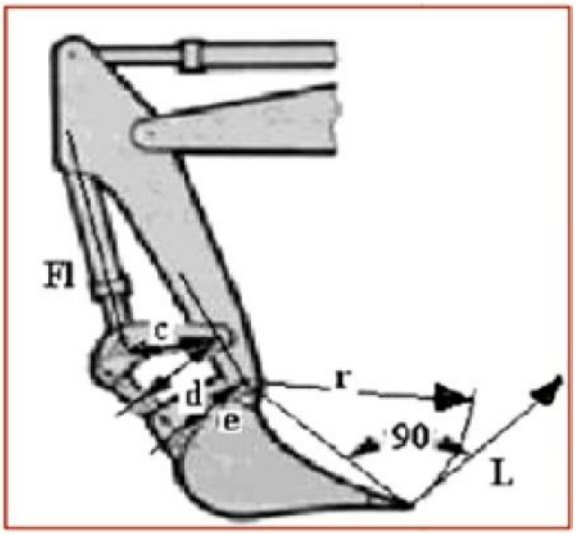


Figure 3: Breakout Force



compared to all other standard model. The breakout force is calculated by SAEJ1179. The SAE provide the breakout and digging force. The optimization is done for various components of assembly and presented in the paper.

Bodur and Zontul (1994) have control the cognitive force for the automation of the land excavation is developed to include the kinematics of the excavator arm. During digging at a certain point on the excavation trajectory, both the crawler and the rotational super-structure bodies are stationary, and thus the kinematic model is reduced to 3 degree of freedom.

FINITE ELEMENT ANALYSIS

FEM Introduction

The Finite Element Method (FEM), sometimes referred to as Finite Element Analysis (FEA), is a computational technique used to obtain approximate solutions of boundary value problems in engineering. Simply stated, a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure.

PROBLEM FORMULATION

This digging task is repetitive in nature and during the operation the entire link mechanism working under the dynamical condition. Some time due to improper controlling of the dynamic forces the backhoe mechanism may failed. Higher damage rates lead to higher maintenance downtime (lower machine availability) which subtracts from the net capacity of the machine to produce (Andrew, 2002).

The excavator mechanism must work reliably under unpredictable working conditions. Poor strength properties of the excavator parts like boom, arm and bucket limit the life expectancy of the excavator. Therefore, excavator parts must be strong enough to cope with caustic working conditions of the excavator (Mehmet, 2005). Terrains are of different kind and exerted sioltool interaction forces may very as per the terrain condition. Therefore it is challanging job to design such a excavator which can work under unpredictable working environment and also prolong all kind of forces without any kind of failure. For design engineer it is not enough to provide rubust design but also taking care of the weight of the attachmet for better controlling during excavation operation.

During the work cycle a backhoe must accelerate, move at constant speed, and decelerate. This time-varying position and orientation of the backhoe is termed as its dynamic behavior. Time-varying torques are applied at the joints (by the joint actuators) to balance out the internal and external forces. The internal forces are caused by motion (velocity and acceleration) of links. Inertial, Coriolis, and frictional forces are some of the internal forces. The external forces are the forces exerted by the environment. These include the “load” and gravitational forces. As a result, links and joints have to withstand stresses caused by force/torque balance across these (Mittal and Nagtath, 2008).

Earth moving process passages huge challenges to scientist and researchers due to the complexicity of the dynamical environment, in particular era of design, dynamics and controlling of the excavation process of an excavator (Bhaveshkumar and Prajapati, 2011).

A GENERAL PROCEDURE FOR FINITE ELEMENT ANALYSIS

Certain steps in formulating a finite element analysis of a physical problem are common to all such analyses, whether structural, heat transfer, fluid flow, or some other problem. These steps are embodied in commercial finite element software packages (some are mentioned in the following paragraphs) and are implicitly incorporated in this text, although we do not necessarily refer to the steps explicitly. The steps are described as follows.

Preprocessing

The user constructs a model of the part to be analyzed in which the geometry is divided into a number of discrete sub regions, or elements, connected at discrete points called nodes. Certain of these nodes will have fixed displacements, and others will have prescribed loads. These models can be extremely time consuming to prepare, and commercial codes vie with one another to have the most user-friendly graphical preprocessor" to assist in this rather tedious chore. Some of these preprocessors can overlay a mesh on a preexisting CAD file, so that finite element analysis can be done conveniently as part of the computerized drafting-and-design process. The preprocessing step is, quite generally, described as defining the model and includes.

- Define the geometric domain of the problem.
- Define the element type(s) to be used.
- Define the material properties of the elements.
- Define the geometric properties of the elements (length, area, and the like).
- Define the element connectivity's (mesh the model).
- Define the physical constraints (boundary conditions).
- Define the loadings.

Solution

During the solution phase, finite element software assembles the governing algebraic equations in matrix form and computes the unknown values of the primary field variable(s). The computed values are then used by back substitution to compute additional, derived variables, such as reaction forces, element stresses, and heat flow. As it is not uncommon for a finite element model to be represented by tens of thousands of equations, special solution techniques are used to reduce data storage requirements and computation time.

For static, linear problems, a wave front solver, based on Gauss elimination, is commonly used. While a complete discussion of the various algorithms is beyond the scope of this text, the interested reader will find a thorough discussion in the Bathe book.

Visualization (Post Processing)

In the earlier days of finite element analysis, the user would pore through reams of numbers generated by the code, listing displacements and stresses at discrete positions within the model. It is easy to miss important trends and hot spots this way, and modern codes use graphical displays to assist in visualizing the results. Typical postprocessor display overlays colored contours representing stress levels on the model, showing a full-field picture. Analysis and evaluation of the solution results is referred to as post processing. Postprocessor software contains sophisticated routines used for sorting, printing, and plotting selected results from a finite element solution.

CONCLUSION

The main objective of this work is to carry out the modeling and FE analysis of an excavator, various software used by researchers like PRO-ENGINEER, CATIA, ANSYS, according to their ease of user friendliness and accuracy of results. The mini hydraulic backhoe excavator attachment is developed to perform excavation task for light duty construction work. Based on static force analysis finite element analysis is carried out for individual parts as well as the whole assembly of the backhoe excavator with and without consideration of welding. It is clearly depicted that the stresses produced in the parts of the backhoe excavator attachment are within the safe limit of the material stresses for the case of with and without consideration of welding.

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