Shape Optimization of an Excavator Bucket with the Help of ANSYS Software

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Abstract- *An excavator is a typical hydraulic heavy-duty human operated machine used in general versatile construction operations, such as digging, ground leveling, carrying loads, dumping loads and straight traction. Excavators (hydraulic) are heavy construction equipment consisting of a boom, dipper (or stick), bucket and cab on a rotating platform known as the house. Excavator bucket tooth must have supporting geometrical shape to penetrate and to endure the digging process on the ground, gravels, stones, or any other abrasive field. In this shape optimization of bucket is critical task in context of digging force developed through actuators during the digging operation. This paper focuses on the evaluation method of bucket capacity and digging forces required to dig the terrain for light duty and heavy duty construction work. Model is exported through ANSYS 15.0 for meshing in analysis software boundary conditions and the forces are applied at the tip of teeth of excavator bucket. Static analysis is done in ANSYS 15.0 analysis software. In this paper the stresses developed at the tip of excavator bucket teeth are calculated. Structural analysis was carried out on the excavator bucket at different widths of teeth such as 25 mm, 30 mm, 35 mm, 40 mm and 45 mm. And the analysis was carried out on three types of materials named Stainless Steel, AISI-1045 and TI Carbide and the action of various stress and strains on the excavator bucket at various loads were investigated.*

Key Words: ANSYS, Excavator bucket, Optimization, stress analysis.

1. INTRODUCTION

Excavator machines are high power machines used in the Mining, Agricultural and Construction industry whose principal functions are Digging (material removing), Ground leveling and material transport operations. Backhoe attachment is rear part of excavator machine. The backhoe attachment is subjected to static as well as dynamic forces. This project work includes static force analysis and design modification of backhoe assembly of excavator.

One of the heavy equipment which is commonly used in digging is excavator. Excavator is heavy equipment used in construction and mining industries to excavate holes and build foundations and other things. Excavator bucket is made of solid steel and is generally equipped with protruding teeth on its cutting side to breakdown hard material and prevent wear and damage of bucket. Excavator bucket teeth must have supporting loading capacity of materials such as wet ground, rocks and abrasive field caused by the nature of the ground when the bucket teeth breakdowns the material. Alloy steel is commonly used to make excavator bucket teeth

Applications for excavator in India include use as a utility machine at large construction sites (roads and dams for example) and urban infrastructure projects as well as the loading of hoppers and trucks, trenching, the cleaning of canals and ditches, general excavation, solid waste management and even demolition and mining work. An excavator is an engineering vehicle consisting of a bucket with cabin for the operator and tracked system for movement and engine is used for power generation. Hydraulic system is used for operation of the machine while digging or moving the material.

Excavation is of prime importance in mining, earth removal and general earthworks. Hydraulic cylinders apply forces to boom, arm and the bucket to actuate the mechanism. Depending on the mechanism position, working pressure and diameter of the hydraulic cylinders, the amount of excavation force changes. In practice, boom cylinders are used for adjusting the bucket position not for digging. They may be used for lifting purpose. While arm and bucket cylinder is used for excavation. Thus, calculation of digging force must be carried out separately when arm or bucket cylinder is the active cylinder. The maximum digging forces are the digging forces that can be exerted at the outermost cutting point. These forces are calculated by applying working circuit pressure to the cylinder(s) providing the digging force without exceeding holding circuit pressure in any other.

As the use of excavator in day to day life is increasing for many purposes but the applicable site is not inspected properly due urgency of work by the owner or the contractor due to which improper handling of it leads to damage of the ground engaging tool i.e. bucket. The bucket of the excavator is main contacting part of it which comes in contact with the soil and rocks while doing excavation at various sites. So in this case sometimes the bucket gets damage due to some improper handling by the operators, which leads to the damage .Here I calculate the stresses in bucket by analytically and Finite analysis approach and then compares their results. Here needs to modify bucket shape for smooth flow of material and to improve machine performance.

Direct contact of metal components and the ground requires an alloy that has the characteristic of toughness and high abrasive resistance. High hardness value is also required on the surface that loads moving materials and even hard materials to manufacture grinding equipment for mining industry. In an excavator, the digger and lifter part is called an excavator bucket. The tip part of the bucket which plays the claw role is called bucket teeth which are the most likely part to fail when the excavator is operated. Generally, bucket teeth design is based on the use of bucket teeth on soft or hard media.

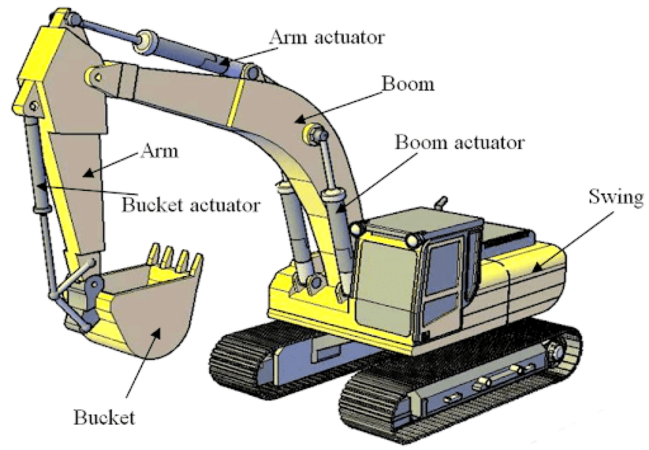

Fig.1.1 A typical Excavator Structure

Normally excavators are working under worst working conditions. Due to severe working conditions, excavator parts are subjected to high loads and must work reliably under unpredictable working conditions. Thus, it is necessary for the designers to provide not only an equipment of maximum reliability but also of minimum weight and cost, keeping design safe under all loading conditions. The force analysis and strength analysis is important steps in the design of excavator parts

2. RELATED WORK

[1] **Rosen Mitrev and et.al** in their paper they have studied the dynamic stability of a hydraulic excavator during performing lifting operations. The developed dynamic model with six degrees of freedom considers the base body elastic connection with the terrain, the front digging manipulator links, and the presence of the freely suspended payload swinging. They have found that the excavator overturning stability while following a vertical straight-line trajectory decreases during the motion from the higher to the lower part of the trajectory. If the stability coefficient is close to 1, the payload swinging can cause the separation of a support from the terrain; nevertheless, they have found that the excavator overturning stability can be restored.

[2] **Bilal Pirmahamad Shaikh and et.al** in their paper they taken the maximum digging force condition as the boundary condition and loading condition to carry out static finite element analysis for different excavator bucket tooth. They have found that the Stresses below yield strength obey Hook's law, so deformation in elastic limits. From results it can be seen that stresses are still below safe stress/ allowable stress value so more material can be removed. They have found in the results that the tiger and twin tiger teeth stresses are above safe stresses.

[3] **B. Govinda Reddy and et.al** in their paper they have done the analytical and Ansys results percentage error. The stress at the Tip of teeth of an Excavator bucket is calculated 86.39 MPA and stress due to shearing of rivet is calculated 187.67 MPA by analytically. The stress at the tip of the teeth is calculated 112.98 MPA and stress due to shearing of rivet 157.47 is calculated. Percentage error between analytical result and Ansys result are 13.69 % and 6.72 %. From the above results they have suggested that the bucket used for the excavation purpose should be properly checked for its application on the basis of the soil strata.

[4] **Bhaveshkumar Patel** the prediction of digging forces and can be applied for autonomous operation of excavation task. The evaluated digging forces can be used as boundary condition and loading conditions to carry out Finite Element Analysis of the backhoe mechanism for strength and stress analysis. An generalized breakout force and digging force model also developed using the fundamentals of kinematics of backhoe.

[5] **Manisha P. Tupkaret** the objective of this paper is to design an excavator bucket by using CREO-parametric 2.0 software. Model is exported through IGES file format for meshing in analysis software Boundary conditions and the forces are applied at the tip of teeth of excavator bucket. Static analysis is done in ANSYS 13.0 analysis software. In this paper the stresses developed at the tip of excavator bucket teeth are calculated. Percentage error between stress Analytical result and stress ANSYS result are calculated.

[6] **Sujit Lomate and et.al** this paper basically focused on an Analysis and Optimization of Excavator Bucket. The results were supported with an experimental validation for verifying the actual distortion and FEA results. Following are concluding remarks based on the analysis

performed on bucket model & Bucket validation at ARAI. Model of Bucket is analysed under 4 different loading conditions to find out the bucket distortion, and bucket distortion is compared with regular bucket. It is observed that the stresses in 1.8 cum design when analysed for 1/3 offset and for full offset are lesser than 1.9 cum Current production bucket.

[7] **Chinta Ranjeet Kumar and et.al** in their paper the main changes in the model are done by adding rectangular ribs, round ribs and half sphere ribs to the inner surface of the bucket and also EN19 Steel material was replaced with AISI1059 Carbon Steel for better results. Static and buckling analysis on the excavator bucket is done. By observing the analysis results, the stress values for half sphere ribs are less than other three models. When, they compare the results for materials, the stress value is less for AISI 1059 Carbon steel and also its weight is less compared with EN19 Steel.

[8] **Swapnil S. Nishane and et.al** in their paper By modelling and analysis of backhoe excavator bucket they have been observed that, the values of von-mises or equivalent stresses for existing and optimized bucket become less difference, but the area of stress in optimized backhoe excavator bucket is reduced as compared to existing one.

[9] **Khedkar Y and et.al** in their paper Analytical soil-tool interaction models are utilized to calculate resistive forces exerted during digging operations. The digging force is higher than the resistive force so the bucket design is proficient for digging. From the graphs, it's clear that resistive force is increasing as the tool depth below the soil, bucket width and rack angle so it's necessary to select optimum value of bucket width and rack angle while designing bucket. With the static force analysis, we come to know about forces acting at joints of the bucket for each angle of lift and digging.

[10] **Rahul Mishra and et.al** in their paper the capacity of bucket has been calculated according to SAEJ296. The bucket specification is the most superior when compared to all other standard model. The breakout force is calculated by SAEJ1179. The SAE provide the breakout and digging force. Formax. breakout force condition but for autonomous application it is important to understand. Which are improved bucket geometry for more efficient digging and loading of material. And heavy-duty robust construction for increased strength and durability.

[11] **R M Dhawale and S R Wagh** worked on "Finite Element Analysis of Components Of Excavator Arm. Various analysis done on components of excavator arm and there are various forces affects on components of excavator arm. 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.

2.1 Excavator Bucket

A bucket is a specialized container attached to a machine, as compared to a bucket adapted for manual use by a human being. It is a bulk material handling component. The bucket has an inner volume as compared to other types of machine attachments like blades or shovels. The bucket could be attached to the lifting hook of a crane, at the end of the arm of an excavating machine, to the wires of a dragline excavator, to the arms of a power shovel or a tractor equipped with a backhoe loader or to a loader, or to a dredge. The name "bucket" may have been coined from buckets used in water wheels, or used in water turbines or in similar-looking devices. Buckets in mechanical engineering can have a distinct quality from the traditional bucket (pail) whose purpose is to contain things. Larger versions of this type of bucket equip bucket trucks to contain human beings, buckets in water-hauling systems in mines or, for instance, in helicopter buckets to hold water to combat fires. Two other types of mechanical buckets can be distinguished according to the final destination of the device they equip: energy-consumer systems like excavators or energy-capturer systems like water bucket wheels or turbines. Buckets exist in a variety of sizes or shapes. They can be quite large like those equipping hulett cranes, used to discharge ore out of cargo ships in harbours or very small such as those used by deep-sea exploration vehicles. The shape of the bucket can vary from the truncated conical shape of an actual bucket to more scoop-like or spoon-like shapes akin to water turbines. The cross section can be round or square.

Excavator buckets are digging attachments with teeth that can be fixed to the arm of an excavator. The buckets are controlled by the excavator operator using controls in the cabin. There are different types of excavator buckets that are used depending on where the digging has to be done. Excavator buckets can also be used to move dirt or load dump trucks for transportation to dumping sites. Excavators are used in conventional trenching methods for laying pipelines and also used for digging trial pits for geotechnical investigation. The construction industry is wider than what you have imagined it was. By simply looking at the machineries and equipment being used in it, you can definitely say that it is a huge world to work into. But no matter what tasks are needed to be done, the presence of heavy machines like the excavator and excavator attachments can it all easy and simple to complete. Being a compact machine, an excavator is the best tool to use when it comes to starting on a construction project. The excavator is simple to operate even if it appears to be a difficult machine. You will actually require constant practice in order that you can easily run this machine and effectively complete tasks for your project. The best thing about an excavator is that it may make use of excavator attachments in order that it can further do more tasks.

Following image shows the actual model of the bucket which is to be analysed for the bucket capacity, volume, forces and then optimize it.

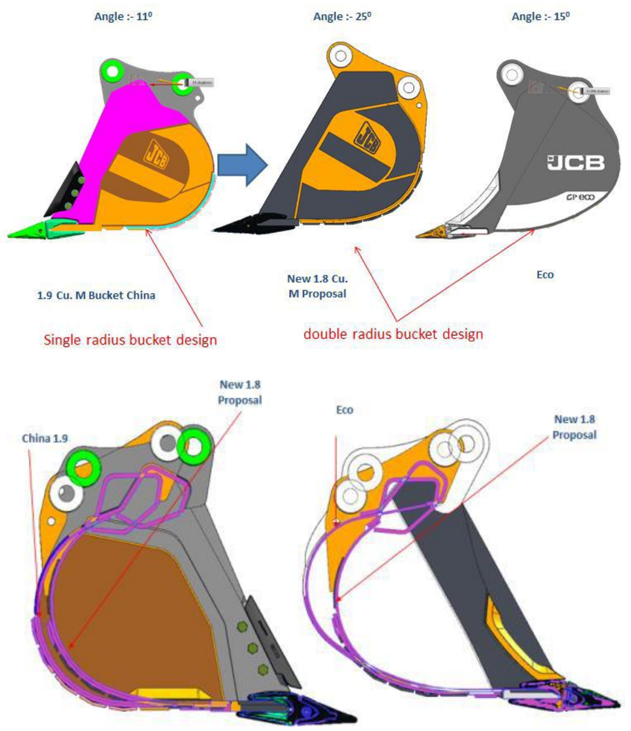

Fig. 3.1 Bucket shape optimization

2.2 Bucket Capacity

Bucket capacity is a measure of the maximum volume of the material that can be accommodated inside the bucket of the backhoe excavator. Bucket capacity can be either measured in struck capacity or heaped capacity. Globally two standards used to determine the heaped capacity, are: (i) SAE J296: "Mini excavator and backhoe bucket volumetric rating", an American standard (ii) CECE (Committee of European Construction Equipment) section VI, a European standard [2]. The struck capacity directly measured from the 3D model of the backhoe bucket excavator for our case as shown in Fig.3.1 by following the SAE J296 standards [2]. As can be seen from the left side of the Fig. 31, P Area is the area bounded by struck plane (blue line) and side protector (red curve).

3. METHODOLOGY

3.1 Shape Optimization of Excavator Bucket using ANSYS software

In the era of globalization and tough competition, the use of machines is increasing for the earth moving works considerable attention has been focused on designing of the earth moving equipment's. 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. Although excavation is ubiquitous in the construction industry, most day-to-day operations proceed on technology that is decades old— technology that has not kept pace with other industries. A recent trend towards greater automation of excavation machines reflects a larger movement in the construction industry to improve efficiency. Currently, human operators require ten to fifteen years of experience before they can be considered experts.

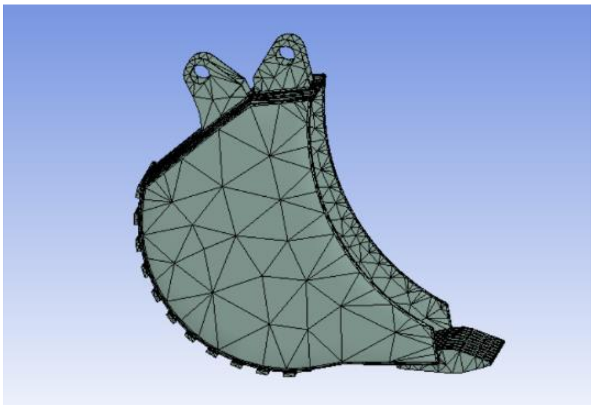

Fig 4.1 Generation of mesh of bucket

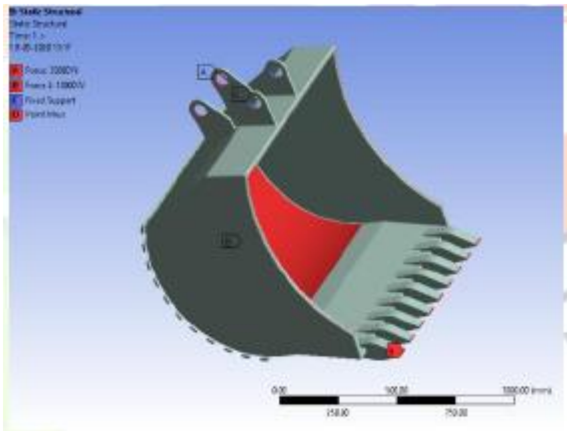

Fig 4.2 Boundary conditions of bucket

Their work is often dirty, strenuous and repetitive. Autonomous excavation has attracted interest because of the potential for increased productivity and lower labour costs. This research concerns the problem of automating a hydraulic excavator for mass excavation, where tons of earth are excavated and loaded into trucks. This application is commonly found in many constructions and mining scenarios. In such applications, fast operational speed of these machines is desired, because it directly translates to increased productivity.

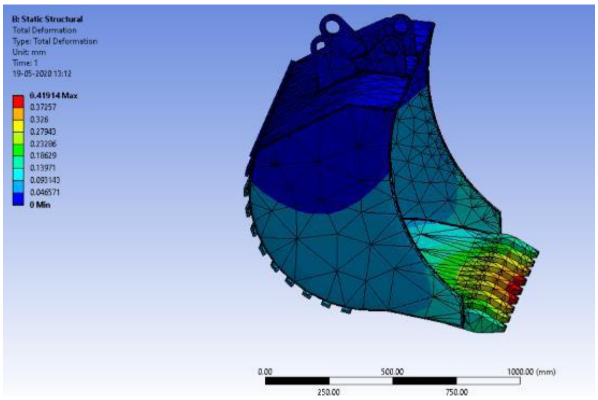

Fig 4.3 Total deformation of bucket

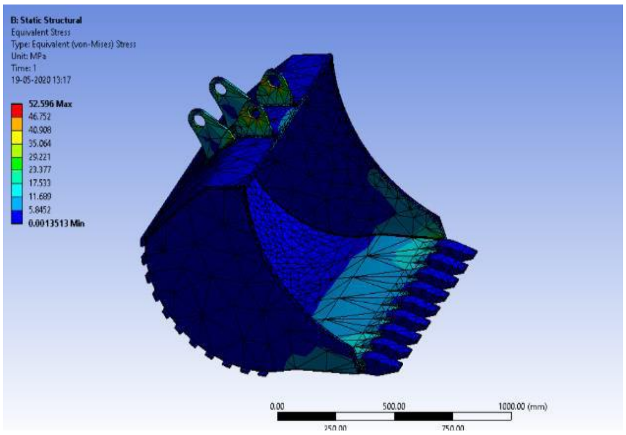

Fig 4.4 Von-misses stresses of bucket

The above figures show the results of the static structural analysis of bucket. The applied load on the bucket teeth tip is 5000N. The deformation developed is less than the thickness of the teeth of the bucket, whereas the deformation is 0.0041mm and the maximum von-misses stress is developed at the cylinder mounting. The developed stress due to the loads is 52.71N/mm2 is less than the yield strength of the material. The allowable yield strength of the material is 450 Mpa.

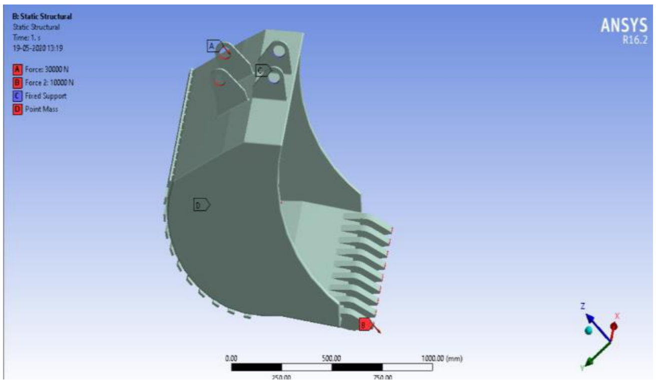

Fig 4.5 Boundary conditions of excavator

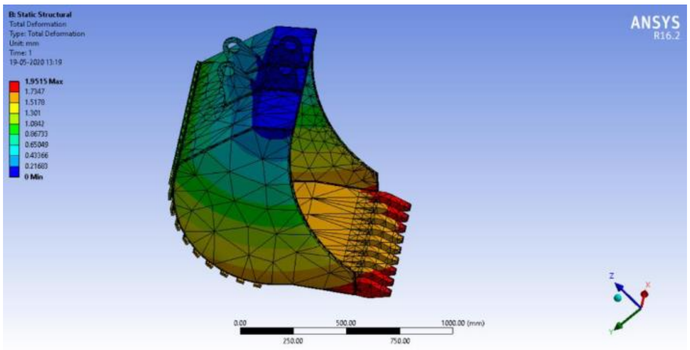

Fig 4.6 Total deformation of bucket

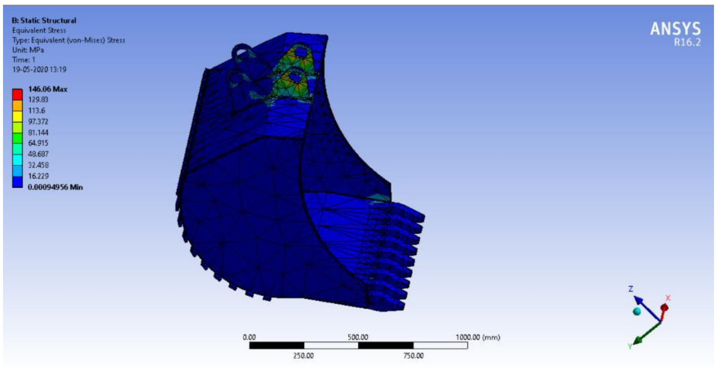

Fig 4.7 Von-misses stresses

The above figures show the results of the static structural analysis of bucket. The applied load is tangential to the bucket teeth tip. The deformation developed is less than the thickness of the teeth of the bucket, whereas the deformation is 1.951mm and the maximum von-misses stress is developed at the cylinder mounting. The developed stress due to the loads is 146.06N/mm2 is less than the yield strength of the material. The yield strength of the material is 450 Mpa.

4. CONCLUSION

The seminar basically focused on Shape Optimization of Excavator Bucket with the help of ANSYS software. The analysis of chassis model was done in ANSYS 15.0 Workbench. The results were supported with an experimental validation for verifying the actual distortion. Following are concluding remarks based on the analysis performed on bucket model & Bucket validation at ARAI. Model of Bucket is analyzed under 4 different loading conditions to find out the bucket distortion, and bucket distortion is compared with regular bucket. It is observed that the stresses in 1.8 cum design when analyzed for 1/3 offset and for full offset are lesser than 1.9 cum Current production bucket.

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