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Fatigue Analysis and Design Optimization of Excavator Bucket

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Abstract

There is rapid growth in the earth moving machine industries as the construction work is rapidly growing is assured through the high performance of construction machines. This paper focuses on the evaluation method of digging forces required to dig the terrene for light duty construction work. This methods gives the force calculation and further it is used for the carrying out the fatigue analysis to calculate fatigue life of bucket and its failure. Further the work regarding the optimization of bucket to give maximum fatigue life for the digging at the desired force conditions. An analytical approach provided for static force analysis of excavator bucket.

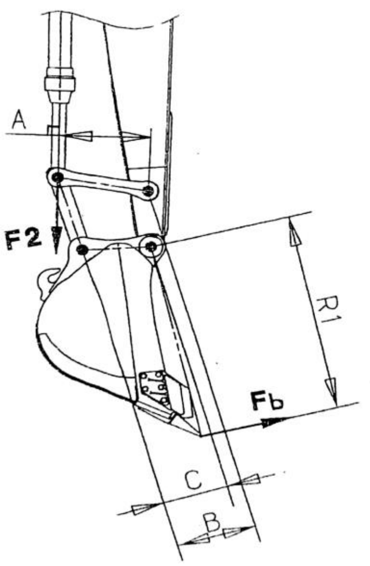
Keywords: digging forces, fatigue analysis of excavator bucket, optimization of excavator bucket.

I. Introduction

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. "Applications for backhoe 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 backhoe with cabin for the operator and wheeled or 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.

II. Calculation of bucket digging and arm digging forces

Sign Explanation



Bucket Digging Force :

Bucket digging force is defined as maximum digging force due to bucket cylinder in tangential direction at bucket tooth.
Pressure of Bucket Cylinder :
It is the pressure of bucket cylinder according to the operation pressure of hydraulic oil, it is depend on the next formulation : $F_2 = (\frac{\pi}{4}) D_b^2 * P_b$

Bucket digging force :

$$F_b = \frac{F2*A*C}{R1*B}$$

Values Found by Actual Practical Observation :
A= 600mm
B= 800mm
C= 470mm
R1= 1300mm
D_b= 115mm
P_b= 0.049Mpa

Calculations :

$$F_2 = (\frac{\pi}{4}) D_b^2 * P_b = (\frac{\pi}{4})*(115)^2*(0.049) = 508.95 \text{ kN}$$

Hence,

$$F_b = \frac{F2*A*C}{R1*B} = \frac{508.95*600*470}{1300*800} = 138\ kN.$$

Bucket digging force = 138kN

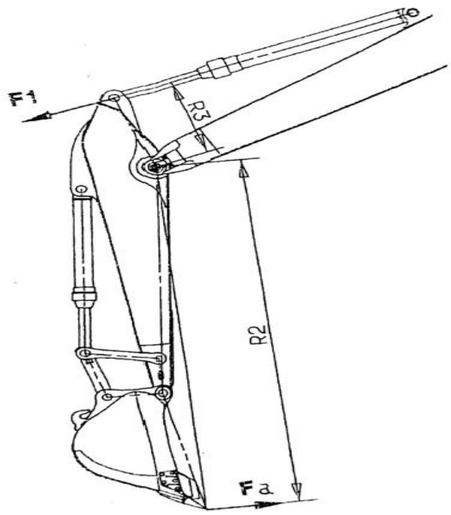
Arm Digging Force:

Arm digging force is defined as maximum digging force due to arm cylinder in tangential direction at bucket tooth in position where bucket tooth force due to bucket cylinder is maximized.

Pressure of arm cylinder:

It is the pressure of arm cylinder according to the working pressure of hydraulic oil, and it is depend on the next formulation:

Sign Explanation



$$F_1 = (\frac{\pi}{4}) D_a^2 * P_a$$

Arm digging force :

$$F_b = \frac{F1*R3}{R2}$$

Values Found by Actual Practical Observation :

R2= 3700mm

R3= 650mm

D_a= 135mm

P_a= 0.049Mpa

Calculations :

$$F_1 = (\frac{\pi}{4}) D_a^2 * P_a = (\frac{\pi}{4})*(135)^2*(0.049) = 701.38kN$$

Hence,

$$F_b = \frac{F1*R3}{R2} = \frac{701.38*650}{3700} = 123.21kN$$

Arm digging force = 123.21kN

Material Properties required for analysis :

1) SM50A:

This steel material is used for all the plates or sheets of bucket.

Mechanical Properties :1) Young's Modulus : $2*10^5$ MPa

2) Tensile Strength : 800 MPa

3) Yield Strength : 450 MPa

4) Elongation : 8-25%

Physical Properties:

1) Density : 7700 kg/m^3

2) SCNCrM2B:

This is low alloy steel used for the tooth of the bucket.

It contains proportion of materials as C=0.25-.35%,Si=0.08%,Mn=1.00%,Ni=1.6-2% Cr=0.3-0.9%,Mo=0.15-0.35.

Mechanical Properties :

1) Young's Modulus : $2*10^5$ MPa

2) Tensile Strength : 880 MPa

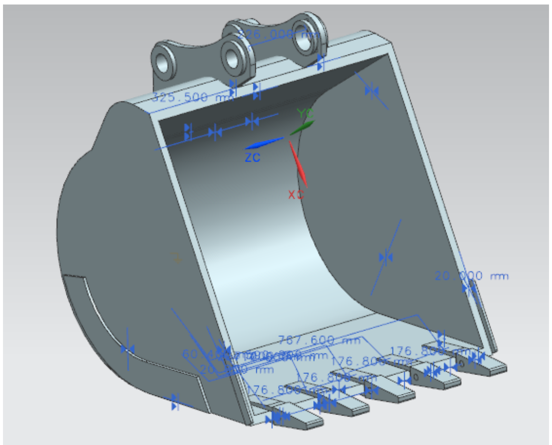
3) Yield Strength : 685MPa

4) Elongation : 9%

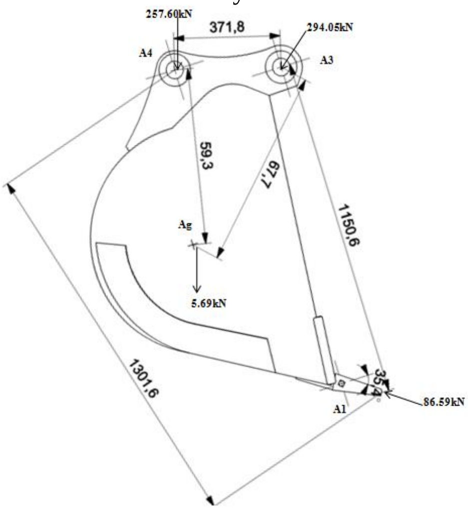
Physical Properties:

1) Density : 7700 kg/m^3

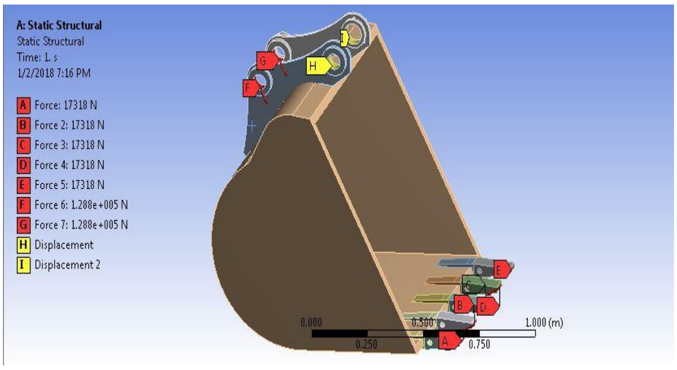
3D Model of bucket



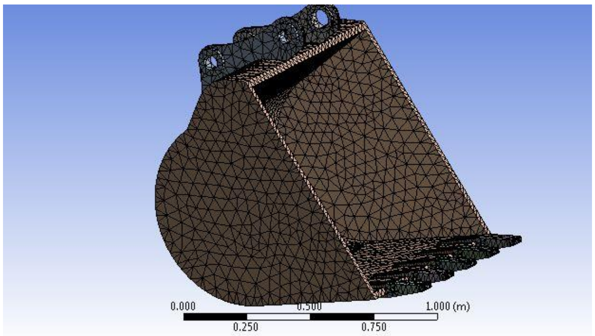
Static Force Analysis :



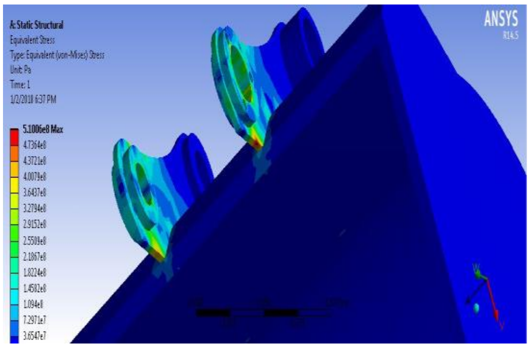
II. Analysis Results For Bucket For Dynamic Loading



Boundary Conditions and force application



Mesh View Of Bucket



Von Misses stresses in bucket

Fatigue life calculation:

By using Goodman's Fatigue life calculation method prediction of fatigue life as:

Mean Stress(X) = $\frac{\sigma max+\sigma min}{2} = \frac{510.06+36.54}{2}$ = 273.27 MPa

Alternating Stress(Y) = $\frac{\sigma max-\sigma min}{2} = \frac{510.06-36.54}{2}$ = 236.73 MPa

Now,

Slope (m) = $\frac{\sigma alternate}{\sigma mean} = \frac{236.73}{273.27}$ = 0.86

Coordinate (Y1) = Endurance limit-mX=400-(0.86*273.27) = 164.98 MPa

Margin of Safety = $\frac{Y1}{Y} = \frac{164.98}{236.73}$ = 0.69

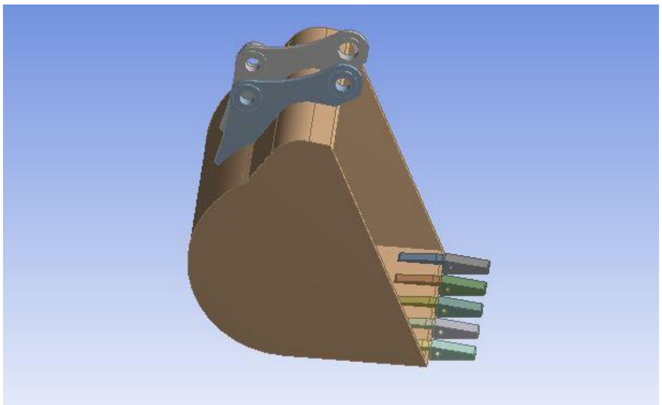
Margin of Safety < 1 so that design is not safe

Fatigue Life =(1-(1/Margin of safety)) = 449259cycles

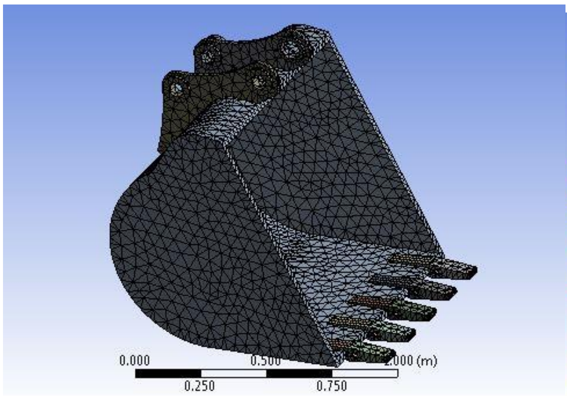
= 121.30hrs

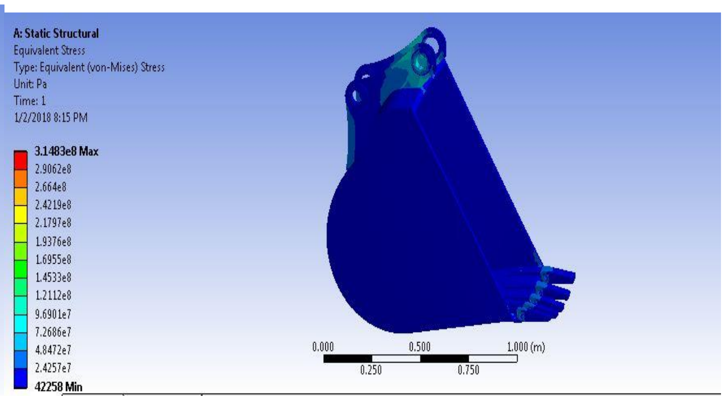
IV Optimization of Bucket

From the above calculations and results we found that the life of the bucket is minimum and which is far below 200hrs.This state of bucket is non-desirable for that purpose there is need of optimization of bucket to give life above at least 1000hrs. Optimization is the process in which we are going to find out the places which are going failed during stress coming on it and again design those places in better way which will give us maximum better results. By studying the above all results we found that maximum stress is come at lugs of the bucket and that is the reason of failure of the bucket. Now we are optimizing that bucket by increasing the width or thickness of bucket lugs by 4mm each also doing some radial changes at the end of lug and decreasing chamfer at the end. Also for better strength we are going to increase the welding thickness so that we will achieve best result. Now let's see further the optimization results for the bucket as :



Optimized bucket model





Mesh View of Optimized Bucket

Von Misses stress view of Optimized Bucket

Fatigue life calculation:

By using Goodman's Fatigue life calculation method prediction of fatigue life as :

Mean Stress(X) = $\frac{\sigma max+\sigma min}{2} = \frac{314.83+0.0422}{2}$ = 157.43 MPa

Alternating Stress(Y) = $\frac{\sigma max-\sigma min}{2} = \frac{314.83-0.0422}{2}$ = 157.39 MPa

Now,

Slope(m) = $\frac{\sigma alternate}{\sigma mean} = \frac{157.39}{157.43}$ = 0.99

Coordinate(Y1) = Endurance limit-mX=450-(0.99*157.43) = 294.14 MPa

Margin of Safety = $\frac{Y1}{Y} = \frac{294.14}{157.39}$ = 1.86

Margin of Safety > 1 so that design is safe

Fatigue Life =(1-(1/Margin of safety)) = 4623655cycles

= 1248hrs

V. Conclusion

The excavator bucket is developed to perform excavation task for light duty construction work. The bucket and arm digging forces are found out by calculations .The model is created on Nx-CAD software and used for analysis in Ansys. By using different material properties and based on static force loads, finite element analysis is carried out for excavator bucket. Using stress values the fatigue life is carried out which gives the cycle time life converted to hrs. Also but using online e-fatigue calculator results are validated. By using the results the stress points are carried out and the optimized bucket model is created.

By using that model the fatigue life of bucket calculated which is above 1000hrs which is much desirable and required. By doing actual field work and by visualization method the results are checked and validated. The optimized buckets passes all required criteria to give us best result when tested for more than 200hrs. Hence, the problem occurred with bucket is successfully resolved and tested for best future.

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