Design and Shape Optimization of Excavator Bucket

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Abstract - *Rapidly growing rate of industry of earth moving machines is assured through the high performance construction machineries with complex mechanism and automation of construction activity.An excavator is a typical hydraulic heavy-duty human operated machine used in general versatile construction operations, such as digging, ground levelling, carrying loads, dumping loads and straight traction.In this design 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. This method provides 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 Excavator mechanism for strength and stress analysis. An analytical approach provided for static force analysis of mini hydraulic excavator attachment. The objective of this paper is to design an excavator bucket to get smooth flow of material and to get effective digging forces.*

Key Words: Excavator, optimization, bucket volume calculation, stress analysis.

1. INTRODUCTION

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 [2]. 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.

2.LITERATURE REVIEW

Bhaveshkumar Patel(1) 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.

Design and Analysis of an Excavator Bucket. Manisha P. Tupkaret al .(2) 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.

Catalogs JCB India ltd (3) Analysis methods ,loading conditions, attachment dimensions ,material standards, cylinder pressure, boom arm and link dimensions and all other standard.

3. PROBLEM FORMULATION

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 [2]. 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. Their work is often dirty, strenuous and repetitive [5]. 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.

4. METHODOLOGY-

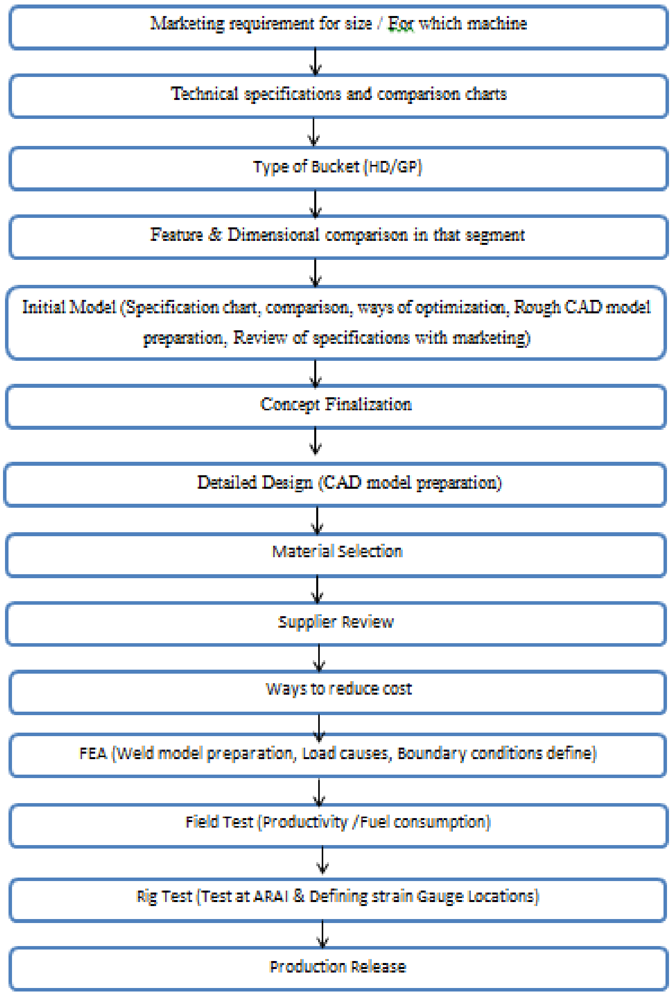


Chart -1 Flow chart

5. BUCKET DESIGN

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

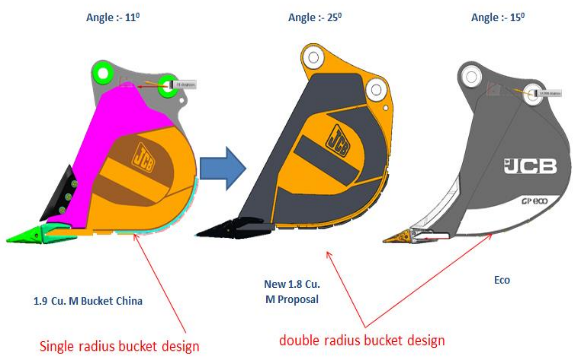


Fig. 1 Bucket shape optimization

5.1. Bucket capacity calculations-

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.1 by following the SAE J296 standards [2]. As can be seen from the left side of the Fig. 1, P Area is the area bounded by struck plane (blue line) and side protector (red curve),

Struck volume, *V*s-The struck volume is calculated as follows.

When the ratio $X/Y \geqslant 12$, the strike plane is used, and then

$$V_s = S_1 \cdot W_1$$

When the ratio *X*/*Y* less than or equal to12, the strike surface is used. This provides a reduction of the struck volume so as to

take the indentation into account. Then

$$V_s = S_2 \cdot W_2 (1 - Y/X)$$

Top volume, *V*t- The *Y* indentation shall not be taken into consideration for the calculation. The *W*4 dimension shall be included for the calculation.The top volume is calculated as follows (see Figure 11).

— For narrow buckets, where $X \geqslant W_4$:

$$V_t = W_4{}^3/6 + \left(W_4{}^2/4\right) \cdot \left(X - W_4\right)$$

— For wide buckets, where $X < W_4$:

$$V_t = X^3/6 + \left(X^2/4\right) \cdot \left(W_4 - X\right)$$

Grab-type bucket -Struck volume, *V*s-The struck volume is calculated as follows

$$V_s = S_3 \cdot W_5$$

Top volume, *V*t- If the operating mechanism of the grab-type bucket is included in the top volume (*V*t), the top volume shall be decreased by the volume of the mechanism (*V*m)

$$V_t = S_4 \cdot W_6 - V_m$$

Expression of volumetric rating -Volumetric rating of hoe- or grab-type bucket-The sum resulting from the volume of the bucket and of the top is calculated as follows: *V*r=*V*s+*V*t

The volumetric rating shall be expressed in cubic meters or in liters and published as a rated capacity in Accordance with this International Standard.

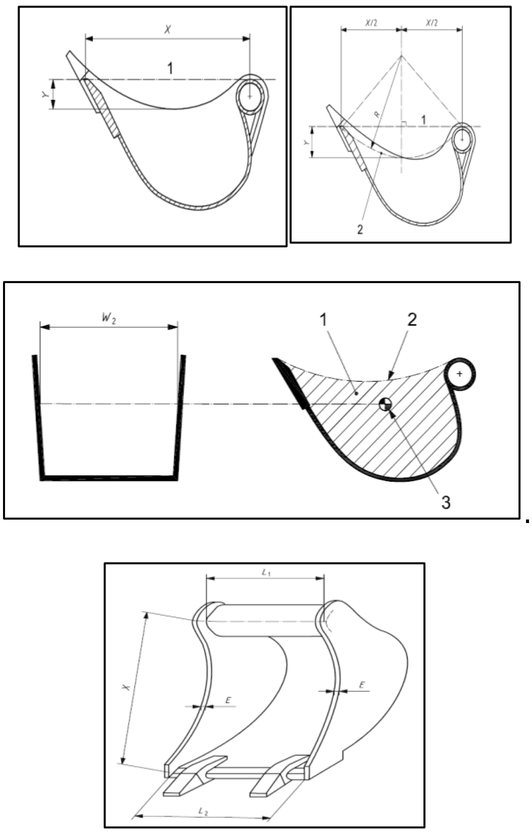


Fig. 2 Bucket capacity

Table -1: Bucket volume calculations

India 1.8 Bucket	Base Model JS 360		Bucket Type	
	Volume Model		HD	
	X (mm)	1273		
	Y(mm)	1		
	R (mm)	Calculated	202566.6 Measured R	
	X/Y	1273.00		
	S2 (mm^2)	727454.1068	Measured Value from CAD	
	W2 (mm)	1710	Width of bucket at CG of S2	
	L1 (mm)	1730		
	L2 (mm)	1750		
	E (mm)	32		
	Stuck Volume = Vs			
	When, X/Y >=12 then use		Vs=S1*W1	
	When X/Y <=12 then use		Vs=S2*W2(1-Y/X)	
	Vs	1243946523 mm^3	1.2439 m^3	
	Heap Volume = Vt			
	When, X>=W4 then	Vt=(W4^3/6)+(W4^2/4)*(X-W4)		
	When, X<W4 then	Vt = (X^3/6)+(X^2/4)*(W4-X)		
	W4 = ((L1+L2)/2)+2*E	1804		
	Here, W4 > X			
	Vt	558947460.9 mm^3	0.5589 m^3	
	Volumetric Rating = Vr			
	Vr= vs + Vt			
	Vr	1802893984 mm^3	1.8029 m^3	

By using equations bucket capacity for the proposed excavator bucket model comes out to be 1.8029 m3

5.2. Wall cut depth-

5.2.1 Calculation of wall cut depth at tooth centre-(New Bucket)

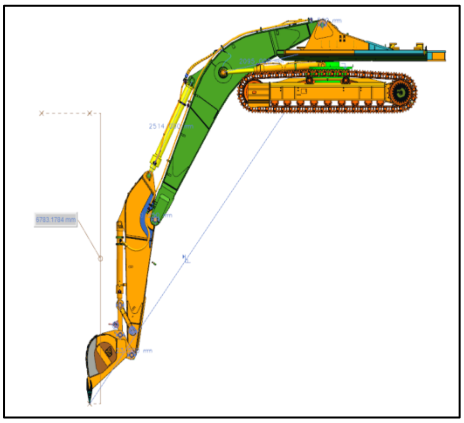


Fig. 3 Bucket wall cut depth from tooth point

5.2.2 Calculation of wall cut depth at toe plate with vertical reference (New Bucket)-

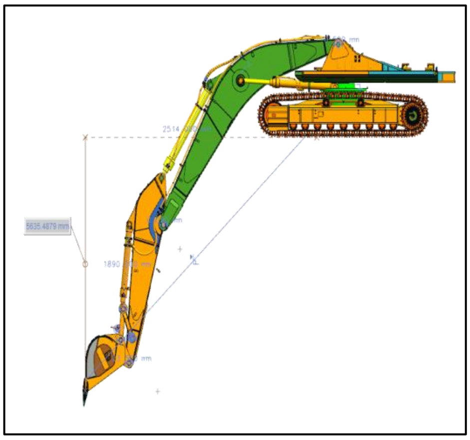


Fig. 4 Bucket wall cut depth from toe plate

Table -2: Bucket wall cut depth comparison

China 1.8	5312
Eco 1.8	6037
New 1.8Cu. M proposal	6783

5.3 Material selection-

Table -3: Material selection table

Major Parts Thickness				
	1.80 Cum Eco.Bucket HD	1.93 Cum Eco.Bucket GP	1.9 China Bucket	1.80 India Bucket
Toe Plate	45	40	50	50
Shell Plate	12	12	14	14
Side Cutter Plate	30	30	32	32
Reinforcement Plate	10	10	16	16

Major Parts Material				
	1.80 Cum Eco.Bucket HD	1.93 Cum Eco.Bucket GP	1.9 China Bucket	1.80 India Bucket
Toe Plate	HARDOX 400	HARDOX 400	HARDOX 400	HARDOX 400
Shell Plate	5000/0103	5000/0103	5000/0103	5000/0103
Side Cutter Plate	HARDOX 400	5000/0103	WH60	HARDOX 400
Reinforcement Plate	HARDOX 400	5000/0103	5000/0103	5000/0103

5.4. Digging forces

Bucket penetration into a material is achieved by the bucket curling force (FB) and arm crowd force (FS). The rating of these digging forces is set by SAE J1179 standard "Hydraulic Excavator and bucket : Digging Forces" [6].These rated digging forces are the forces that can be exerted at the outermost cutting point (that is the tip of the bucket teeth). These forces can be calculated by applying working relief hydraulic pressure to the cylinders providing the digging force.

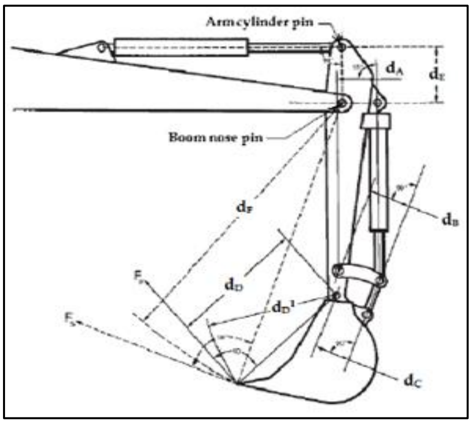


Fig. 5 Forces on bucket

Fig. 6 shows the measurement of bucket curling force FB,arm crowd force FS, the other terms in the figure dA, dB, dC, dD, dD1, dE, and shows the distances as shown in Fig. 2. According to SAE J1179: Maximum radial tooth force due to bucket cylinder (bucket curling force) FB is the digging force generated by the bucket cylinder and tangent to the arc of radius dD

$$F_B = \frac{p \times (\pi/4) D_B{}^2}{d_D} \left(\frac{d_A \times d_C}{d_B} \right) \quad (4)$$

Where DB is the end diameter of the bucket cylinder in(mm) and the working pressure is p in MPa or N/mm2 and other distances are in mm and remains constant. Equation (4) determines the value of the bucket curl or breakout force in N. Now let us determine the maximum radial tooth force due to arm cylinder FS. Maximum tooth force due to arm cylinder is the digging force generated by the arm cylinder and tangent to arc of radius dF.

$$F_S = \frac{p \times (\pi/4) D_A{}^2 \times d_E}{d_F} \quad (5)$$

Where, dF is the sum of bucket tip radius (dD) and the arm link length in mm, and DA is the end diameter of the arm cylinder in mm. When the assembly of proposed 3D model is placed in the maximum breakout force

The calculated breakout Force (Fb) =261.2KN and

Calculated Arm Crowd force (Fs) =248.2KN.

5.5. Comparison of excavator models

Table -4: shows the compares on of physical dimensions, bucket specifications and forces of the designed excavator with the standard excavators.

JS370 1.8Cu. M bucket digging forces								
	With boost pressure (370kg/cm^2)				Without Boost Pressure (354 kg/cm^2)			
	Max. bucket force(kN)	Rated bucket force(kN)	Bucket angle	Arm digging force (kN)	Max. bucket force(kN)	Rated bucket force(kN)	Bucket angle	Arm digging force (kN)
1.8 Cu. M New Proposal 3 Toe plate (ISO6015) (Alf1 = 91.01) (BU1=1400)	266.0	252.7	11.0	185.4	254.5	241.8	11.0	177.3
1.8 Cu. M New Proposal 3 Tooth tip (SAEJ1179) (Alf1 = 100.97) (BU1=1617.86)	230.3	218.8	20.9	179.0	220.4	209.4	20.9	171.3
1.9 Cu. M China - Toe plate (ISO6015) (Alf1 = 100.81) (BU1=1339)	278.1	264.2	30.8	192.8	266.1	252.8	30.8	184.5
1.9 Cu. M China - Tooth tip (SAEJ1179) (Alf1 = 111.85) (BU1=1539.5)	241.9	229.8	31.8	185.4	231.5	219.9	31.8	177.4
1.8 Eco Bucket - Toe plate (ISO6015) (Alf1 = 96.21) (BU1=1385.4)	268.8	255.4	16.2	177.4	257.2	244.3	16.2	178.7
1.8 Eco Bucket - Toe plate (SAEJ1179) (Alf1 = 106.94) (BU1=1569.93)	237.2	225.4	26.9	182.5	227	215.6	26.9	174.6

Table -05 Comparison of bucket parameters

6. FINITE ELEMENT ANALYSIS OF AN EXCAVATOR BUCKET

6.1 FEA procedure in ANSYS

While analyzing the whole excavator attachment modeled in three dimensions in ANSYS the following procedure is used.

1. Export the model / assembly
2. Specify materials
3. Add constraints:
4. Add loads

5. Specify contact conditions:

6. Meshing:

6.2 Load Cases & deformations-

Load 1/3 offset Case

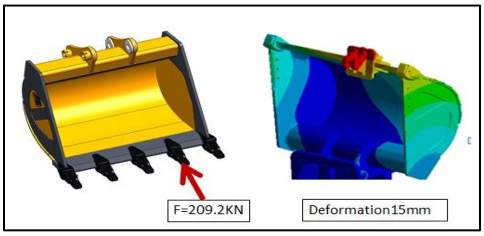
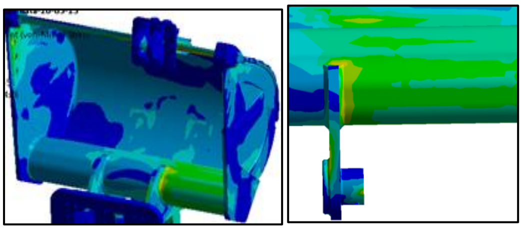


Fig. 6 Bucket deformation at 1/3 load



Von-mises Stresses is done at 200 MPa.

Fig. 7 Von mises stress analysis of bucket at 1/3 load

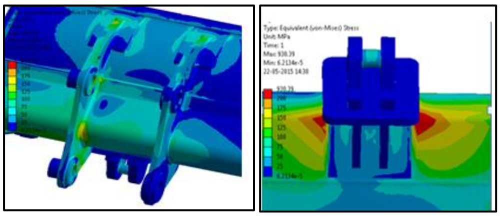
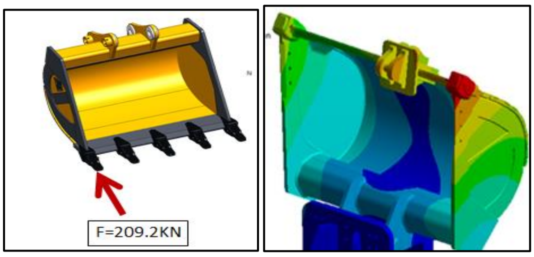


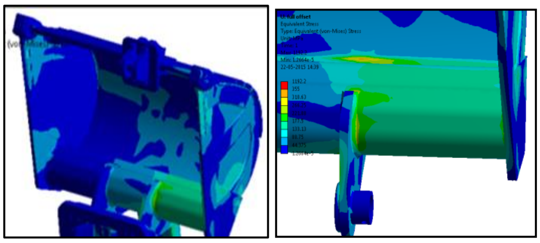
Fig. 12 Von misses stress analysis of bucket at 1/3 load



Total Deformation of 22 mm

Actuator force applied is 209.2 KN

Fig. 8 Bucket deformation at full load



Von-mises Stress analysis at full load

Fig. 9 Von mises stress analysis at full load

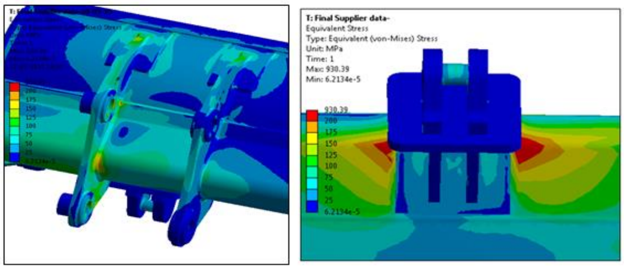


Fig. 10 Von misses stress analysis of bucket at full load

7. COMPARISON OF CURRENT BUCKET AND PROPOSED BUCKET-

Table 5-Bucket comparison

Bucket Type	Deformation at 1/3 Load condition	Deformation at full Load condition	Von mises stress
1.9 Cum current bucket	19mm	26mm	More
1.8 Cum new bucket	15mm	22mm	Less

8. CONCLUSION

1. The Project basically focused on an Analysis and Optimization of Excavator Bucket .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 and FEA results. Following are concluding remarks based on the analysis performed on bucket model & Bucket validation at ARAI.
2. 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 analyzed for 1/3 offset and for full offset are lesser than 1.9 cum Current production bucket

3. In bucket validation we observed that Bucket strength & life is more as compared with previous bucket.

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11) static analysis of mini hydraulic backhoe excavator attachment using fea approach issn 2278 – 0149 www.ijmerr.com ,vol. 1, no. 3, october 2012 © 2012 ijmerr. all rights reserved bhaveshkumar p patel1* and j m prajapati2

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