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Static Analysis of John Deere 310G Backhoe Excavator Structure Using a Finite Element Approach

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Abstract

Backhoe excavator loader is a combination of two useful tools into one machine, on the front of the tractor there is a loader and on the back is a backhoe excavator. Excavator backhoe consists of bucket, arm, boom and swing link. The use of backhoe attachments (bucket, arm, and boom) is very crucial because it works in harsh conditions such as mining, construction, and agriculture, making it very vulnerable to damage that can cause loss of life and costs. So we need a backhoe excavator that is safe to operate. So in this study, discussing modeling the backhoe excavator and performing a stress analysis on the backhoe excavator attachment during digging conditions is useful to determine the safety factor of the backhoe attachment using the finite element method. To model the backhoe excavator attachment, you can use Solidwork CAD software. The results of this study were obtained, obtained on the x-axis A_2 : 54,79 kN, A_3 Arm : -195,19 kN, A_8 : 13,12 kN, A_9 : 164,95 kN, A_{12} : 71,91 kN, BA_4: -38,81 kN, BA_3 : 195,19 kN, BA_{11}: -127,36 kN, BO_2: -54,79 kN, BO_7: -73,32 kN, BO_5: 550,73 kN. A_1 :-532,21 kN. Pada sumbu y A_2 : -60,74 kN, A_3 Arm : -96,79 kN, A_8 86,44 kN, A_9 : 114,35 kN, A_{12} : -43,46 kN, BA_4: 30,57 kN, BA_3 : 96,79 kN, BA_{11}: -127,36 kN, BO_2: 60,74 kN, BO_7: -48 kN, BO_5: -196,65 kN. A_1 : 183,91 kN. Determination of the load as the maximum breakout force configuration limit condition is located at 30° with a maximum von misses stress value on the bucket of 246,86 Mp on the arm of 234,32Mpa, on the boom 200,46Mpa with element size 10 mm. While the maximum von misses stress at 30o, the factor of safety value for the bucket is 1,86, the arm is 2,06, the boom is 1,84, which is still in the safe category so that there is no material failure.

Keywords : Backhoe Excavator Attachment, Finite Element Method, Von Misses Stress, and Factor of Safety

INTRODUCTION

Excavator machines are high-power machines, usually used in the mining, agriculture and construction industries where their main function is digging (removing material), ground leveling operations and transporting materials. Of all the machines used in the mining, agriculture and construction industries, the backhoe excavator loader is the most widely used by contractors for excavation and earthmoving due to its versatility (Thombarer, 2021). When viewed from the structure, the backhoe excavator loader consists of three parts, namely the loader, back attachment, and cabin. One of the main parts of an excavator loader is the back attachment consisting of the boom, arm, and bucket. The use of this back attachment is very crucial in carrying out the work carried out by a backhoe excavator. The operator must know the correct way to operate the excavator backhoe so that the excavator is not easily damaged. The high operation of heavy equipment makes heavy equipment often experience trouble which results in the heavy equipment unit not working optimally. Heavy equipment maintenance must be carried out properly and on a schedule so that it can be used effectively and efficiently to minimize breakdowns. In addition, good maintenance can reduce operational costs in an industry or company that uses heavy equipment (Margaretha, and Bambang, 2020).

The excavator part that often suffers damage is the bucket, but damage can also occur to the excavator arm and boom. The most common damage to the excavator arm is the relationship between the boom and the arm due to the stresses of compression and bending during lifting and digging operations. Compared to the body arm, this section has a smaller cross-sectional area so that it experiences the greatest stress and pressure (Chunlei Yu, et al., 2021).

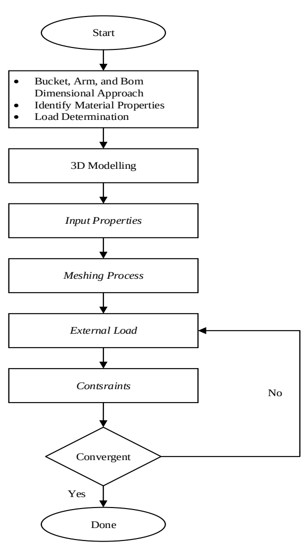
Damage to the backhoe excavator attachment (bucket, arm, and boom) depends on the position of the working mechanism, working pressure and hydraulic cylinder diameter, the amount of digging force is always changing. In practice, the boom silindercylinder used to adjust the position of the bucket not for digging. The backhoe excavator attachment can be used for lifting purposes. When arm and bucket cylinders are used for excavation. Thus, the damage can be calculated in advance how much the force acts, the calculation of the breakout or digging force must be done separately when the arm or bucket cylinder is an active cylinder. The maximum digging force is the digging force that can be applied at the outermost intersection. This force is calculated by applying a working circuit pressure to the cylinder which provides a digging force without exceeding the resistance circuit pressure in other circuits. The weight of components and friction must be excluded from the calculation of this force (Saldana-Robles, 2020). Based on these problems, this research will focus on how to model in 3 dimensions and perform static analysis of the backhoe excavator attachment (bucket, arm, and boom).

METHOD

This study uses the J. Deere 310G Attachment Backhoe Excavator modeling which includes a bucket, boom, and arm with an approach from the original design obtained from the market. The modeling is carried out using Solidworks 2021, after that it is simulated using the Altair Hyperworks finite element method to represent the results of linear static analysis. To get reaction force in bucket, arm and boom simulation. In this simulation, the finite element method is used in Altair Hyperworks using Optistruct.

The research began in July 2021 with a study of the backhoe Excavator J. Deere 310G Attachment modeling literature which includes bucket, boom, and arm in the mechanical engineering computer laboratory. Literature study of CAD and CAE programs in the mechanical engineering computer laboratory. CAD modeling process using Solidworks 2021 in the mechanical engineering computer laboratory. Finite element method simulation and analysis carried out in the mechanical engineering computer laboratory in Diponegoro University.

Research *Flowchart*



RESULT AND DISCUSSION

1. Static Force Calculation Results

The static force at the bucket points is determined by equations 2.15 – 2.19 with a force at breakout 49,4kN.

Table1. Static Force at Joint of The *Bucket*

Joint	Force (kN) Horizontal (X) Components	Force (kN) Vertical (Y) Components
A_4	-38,81	30,57
A_{11}	-156,38	-127,36
A_3	195,19	96,79

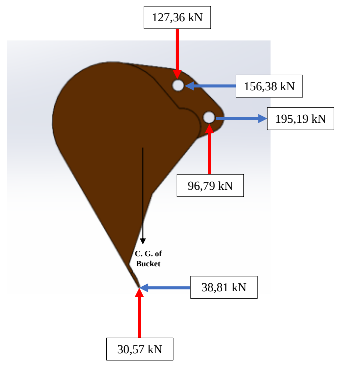


Figure1. Bucket Static Force and Positional Force Reaction 30°

The static force at the arm points is determined by equations 2.20 – 2.26 with the force at point A_3 of A_{3x} = 195,19 kNand A_{3y} = 96,79 kN.

Table2. Static Force at Joint of The*Arm*

Joint	Force (kN) Horizontal (X) Components	Force (kN) Vertical (Y) Components
A3	-195,19	-96,79
A12	71,91	-43,46
A9	164,95	114,35
A8	13,12	86,64
A2	-54,79	-60,74

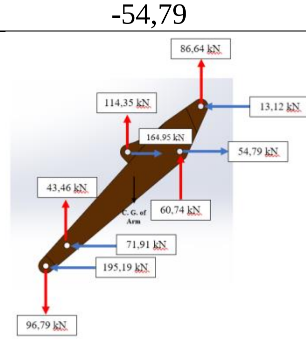


Figure2. Free Body Diagram of Arm and Force Reaction at Position 30°

The static force at the bucket points is determined by equations 2.27 – 2.29 with the force at A_2 being A_{2x} = 54,79kNand A_{2y} = - 60,74kN.

Table3. Static Force at Joint of The Bucket

Joint	Force (KN) Horizontal (X) Components	Force (KN) Vertical (Y) Components
A2	54,79	-60,74
A7	-73,32	-48,00
A5	-550,73	-296,65
A1	532,21	-183,91

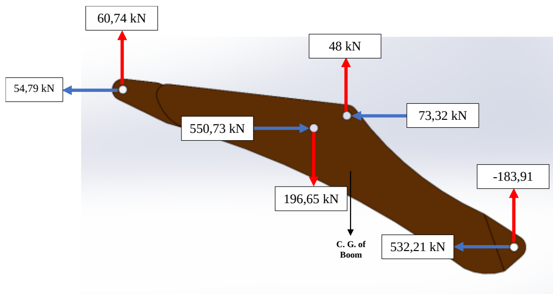


Figure3. Boom Free Body Diagram and Force Reaction at Position 30°

2. Static Linear Simulation Results with *Optistruct*

The bucket was analyzed 5 times with element size variations of 10 mm, 20 mm, 30 mm, 40, and 50 mm. The bucket material uses steel with ASTM A36 standards, based on material properties ASTM A36 has a yield strength of 250 Mpa. The results of the linear static simulation obtained von misses values, namely 246,86Mpa at an element size of 10 mm, 246,61Mpa at an element size of 20 mm, 243.44 Mpa at an element size of 30 mm, 173,26Mpa at an element size of 40 mm, and 135,83Mpa at element size 50 mm. The biggest von misses value in the bucket is 246,86 Mpa.

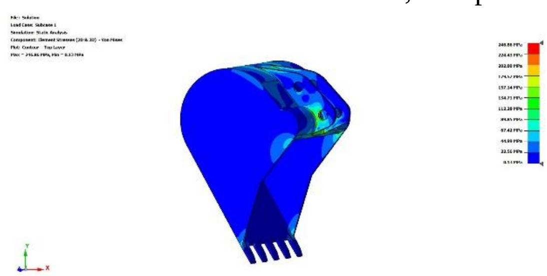
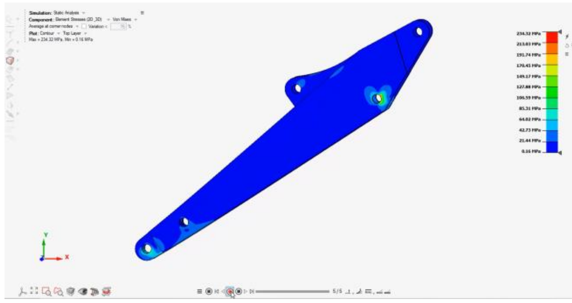


Figure4. Von Misses Bucket Voltage Value at Element Size 10 mm

The arm was analyzed 5 times with element size variations of 10 mm, 20 mm, 30 mm, 40, and 50 mm. Arm material uses steel with ASTM A36 standards, based on material properties ASTM A36 has a yield strength of 250 Mpa. The results of the linear static simulation obtained von misses values, namely 234,32Mpa at element size 10 mm, 165,06Mpa at element size 20 mm, 120,97Mpa at element size 30 mm, 169,21MPa at element size 40 mm, and 134,93 Mpa at element size 50 mm. The greatest value of von misses in the bucket is 234,32MPa.



Gambar 5. Von Misses Arm Strength Value at Element Size 10 mm

The boom was analyzed 5 times with element size variations of 10 mm, 20 mm, 30 mm, 40, and 50 mm. The boom material uses steel with ASTM A36 standards, based on material properties ASTM A36 has a yield strength of 250 Mpa. The results of the linear static simulation obtained von misses values, namely 200,46Mpa at element size 10 mm, 136,60Mpa at element size 20 mm, 134,33Mpa at element size 30 mm, 137,77Mpa at element size 40 mm, and 189,58 Mpa at element size 50 mm. The greatest value of von misses in the bucket is 200,46 MPa.

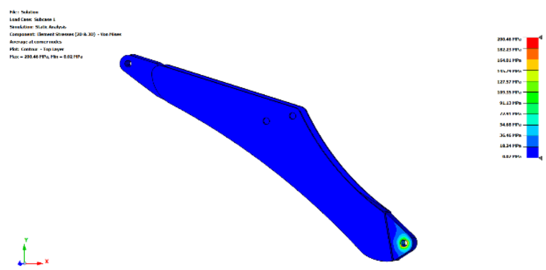


Figure6. Von Misses *Boom*Strength Value at Element Size 10 mm

3. Convergence Test

To determine the appropriate number of elements, a convergence test is carried out first from the bucket, arm, and boom which can be seen in Table 4.4 – Table 4.6 until convergent results are obtained for each element increase by gradually improving the mesh and in certain areas. In the convergence test process, the material used is ASTM A36 according to the material used. The graph is shown in Figure 4.18. The following is the result of each meshing variation with a maximum elements size of 50 mm to 10 mm.

Table4. Bucket Convergence Test

Convergence Test 30 *Degree*	
Meshing (mm)	Von Misses (Mpa)
50	135,83
40	173,26
30	246,61
20	242,46
10	246,86

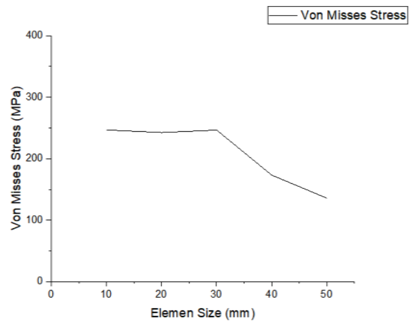


Figure7. Bucket Convergence Test Results

Table5. Arm Convergence Test

Uji Konvergensi 30 *Degree*	
Meshing (mm)	Von Misses (Mpa)
50	134,93
40	169,21
30	120,97
20	165,06
10	234,32

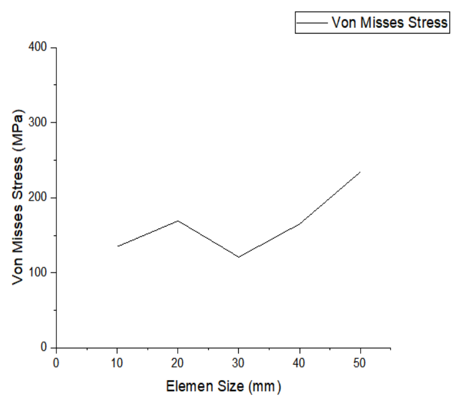


Figure8. ArmConvergence Test Results

Table6. Boom Convergence Test

Convergence Test 30 Degree	
Meshing (mm)	Von Misses (Mpa)
50	189,58
40	137,77
30	134,33
20	136,6
10	200,46

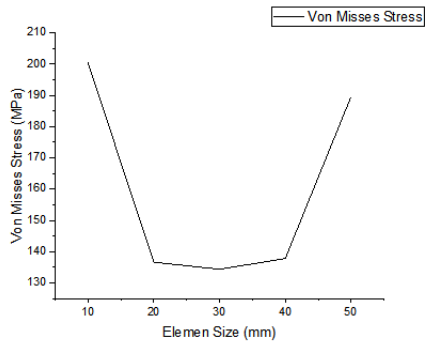


Figure9. Boom Convergence Test Results

4. ***Factor of Safety***

In order to see whether the material used does not fail, a factor of safety analysis is carried out if the von misses stress is less than equal to yield strength($\sigma_{vm} \leq S_y$)then the material can be said to safe, and vice versa if the von misses stress is greater of *yield strength*$(\sigma_{vm} > S_y)$.To get the value of the factor of safety at the 30° position. Can be formulated:

$$FoS = \frac{S_y}{\sigma_{vm}}$$

Table7.*Factor of Safety Bucket*

No	Element Size	Factor of Safety	Note
1	10 mm	1,01	*Safe* $(\sigma_{vm} \leq S_y)$
2	20 mm	1,03	*Safe* $(\sigma_{vm} \leq S_y)$
3	30 mm	1,01	*Safe* $(\sigma_{vm} \leq S_y)$
4	40 mm	1,44	*Safe* $(\sigma_{vm} \leq S_y)$
5	50 mm	1,84	*Safe* $(\sigma_{vm} \leq S_y)$

Table8. *Factor of Safety Arm*

No	Element Size	Factor of Safety	Note
1	10 mm	1,07	Safe (σ_vm≤S_y)
2	20 mm	1,05	Safe (σ_vm≤S_y)
3	30 mm	2,06	Safe (σ_vm≤S_y)
4	40 mm	1,5	Safe (σ_vm≤S_y)

5	50 mm	1,85	Safe (σ_vm≤S_y)

Table9.*Factor of Safety Boom*

No	Element Size	Factor of Safety	Note
1	10 mm	1,32	Safe (σ_vm≤S_y)
2	20 mm	1,81	Safe (σ_vm≤S_y)
3	30 mm	1,86	Safe (σ_vm≤S_y)
4	40 mm	1,81	Safe (σ_vm≤S_y)
5	50 mm	1,25	Safe (σ_vm≤S_y)

CONCLUSION

Based on the research that has been done, there are conclusions including to model the backhoe excavator attachment using CAD Solidwork software. Determination of the load as the maximum breakout force configuration limit condition is located at 30° with the maximum von misses stress value on the bucket of 246,86Mpa, on the arm of 234,32Mpa, on the boom 200,46Mpa with element size 10 mm. For the maximum von misses stress at 30°, the factor of safety value for the bucket is 1,86, the arm is 2,06, the boom is 1,84, which is still in the safe category so there is no material failure.

Further research can develop the design optimization of the bucket, arm and boom. Adding configuration variations such as 0°, 45°, 60°, and 90° for maximum analysis, using a computer with an AMD Ryzen / core i7 processor.

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