DESIGN AND ANALYSIS OF DETACHABLE TYPE BACKHOE AND LOADER

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Abstract: **In this project a detachable type backhoe components are designed and analysed using ANSYS so that it can be mounted over an agricultural tractor and can be used for trenching, digging etc. This design makes backhoe compact in size and shape so that it is fitted inside the tractor. This can be used as a special attachment to the tractor like other attachments like driller, slicer, truck etc. This paper deals with the design of backhoe components, loader components and special chassis for the tractor for a limited load of 2000N backhoe and 6000N loader. This has hydraulic unit which is selected to run by the tractor engine power of 50Hp whereas the original backhoe has 60Hp. It is made as a special detachable attachment so that the load is limited when compared to original backhoe. The design process is carried out from determining the component dimensions that are required to withstand the load by both analytical calculations and software modelling. The components are 3D modelled using CREO PARAMETRIC modelling software and then structural analysis is carried out over the components using ANSYS.**

Keywords: - **Backhoe, Loader, BOOM, Stick, Bucket, etc**.

I. INTRODUCTION

Backhoe loaders are very powerful and versatile equipment's they can perform many tasks, like lifting and moving supplies or digging earth etc. So far many researches have been carried out in improvisation of backhoe by changing its size, orientation, and materials used in it. These were carried out on the basis of cost effectiveness and for better utilization of the power. Since these backhoes are mainly used for large scale and heavy industrial work these are huge in size and they can be used only for limited purposes. Based on this feedback this research is been carried out for designing a detachable type backhoe. So the tractor can be used as a multipurpose equipment.

A. Components in Backhoe and Loader

The backhoe is the most important part the backhoe loader. It has three segments are viz. Boom, stick and bucket**.** This arrangement is very similar to human arm. Human arm has three segments - upper arm, forearm and hand. The backhoe segments are connected by three joints, comparable to your wrist, elbow and shoulder. The backhoe moves in pretty much the same way as your arm. In loader Boom and stick are the main components.

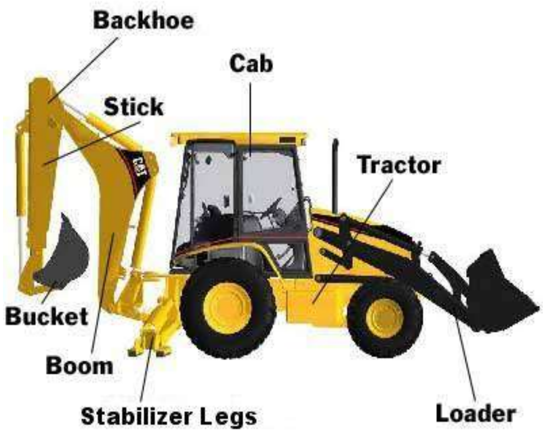

FIG.1 Backhoe Loader Components

The stabilizers keep the tractor steady, minimizing the jostling effect of digging with the backhoe. They also secure the tractor so that it won't slip into the ditch or hole. There are two kinds of stabilizer legs they are inclined stabilizer and vertical stabilizers.

Hydraulic systems simply used to transmit forces from point to point through fluid. The fluid that used in most systems is incompressible fluid such as oil. Hydraulic systems in backhoe loader includes: hydraulic power, hydraulic valves, hydraulics in the backhoe, hydraulics in the loader and hydraulic pump.

Levers are rigid bars that transmit force. They pivot around a fulcrum. Levers can either magnify the effort force to move the load force, resulting in a force advantage, or decrease the

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distance the effort force must travel to move the load, resulting in a speed advantage. Class 1 levers are used in the backhoe. This means that the fulcrum is between the load and effort.

B. Moving the Backhoe

Hydraulics, levers and the gear pump are combined to make a backhoe that can be bent and turned in many ways. The three joints in the backhoe can be bent like your shoulder, elbow and wrist. Many hoses run from the pimp up the backhoe to supply oil to the hydraulic rams (pistons). The operator controls the hydraulics in the backhoe with two joysticks.Two hydraulic pistons connect the boom to the tractor. The pistons allow the backhoe to rotate from side to side. When one of them pushes, the other pulls, so that the boom can be swung sideways.

There is also a piston connecting the tractor and boom. Since the boom is a lever, when the piston pushes or pulls it rotates on its fulcrum, which would be its other connection to the tractor. The other end of the boom, along with the rest of the backhoe attached to it, is lifted and lowered like this.

The stick and bucket are moved in the same way, with a hydraulic piston rotating them around the point where they are attached to the previous part of the backhoe. The backhoe has two stabilizer legs to keep the tractor steady when the backhoe is digging. It also prevents the tractor from falling into the hole that is being dug.

II.SCOPE OF THE PROJECT

The main purpose of the project is to design a detachable type backhoe. An extra equipment and can be used for small scale purposes by mounting it over agricultural tractor. The design is carried out for a tractor of power 50 HP which can carry a load of 2000N i.e. 205 Kg approximately by the backhoe and 6000N by the loader.

III PROPOSED METHODOLOGY

The procedure for obtaining the objective of the project is by performing the Analytical calculations for the backhoe and loader components initially with the required loading condition. The bucket is designed using the modelling software meeting the requirement by trial and error method.

The next step is to design the main components of backhoe which are necessary to move the bucket with the design of hydraulic units like Cylinders and piston, etc.

Once the design calculations are carried out the final dimensions are fixed and Modelling of the backhoe and loader is carried out using modelling software like CREO, CREO PARAMETRIC 2.0, and Auto-CAD.

After the completion of parts modelling the individual parts and components are subjected to Structural analysis using Finite Element packages like ANSYS.

Assembling the components are carried out after carrying out the component analysis and the components are structurally analysed till the safe design is obtained.

IV.DESIGN OF BACKHOE COMPONENTS

A. Degrees of Freedom

As the backhoe functions similar to human arm, but DOF in the backhoe mechanism is less than human arm as the human arm has 8 DOF while the backhoe has 4 DOF.

By KutzBach's Criteria

Degrees of Freedom = 3(n-1) – 2J1 – J2

Here

J2= 0, J1 = 16, n= 13

Therefore

Degrees of Freedom = 4

B. Materials Used

Materials are considered based on "Crane Handbook" Design Data and Engineering Information used in the manufacture and applications of Cranes by H.G. Greiner [3] are shown in Table.1.

Table.1 Materials Used

S.No	Components	Material Used	Material Properties
1	Boom	Medium Strength Alloy Steel ASTM – A514	Ultimate Strength = 690 N/mm^2 Yield strength = 450 N/mm^2 Poisson Ratio = .29 Density = 7900 kg/m^3
2	Stick		
3	Bucket		
4	Swinger		
5	Hydraulic cylinder	Mild Steel SA 36 Grade	Ultimate Strength = 450 N/mm^2 Yield strength = 250 N/mm^2 Poisson Ratio = .27 Density = 5600 kg/m^3
6	Cylinder piston		
7	Pin	Hardened carbon steel ASTM –EN8	Ultimate Strength = 841 N/mm^2 Yield strength = 650 N/mm^2 Poisson Ratio = .29 Density = 7850 kg/m^3

C.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.It is calculated based on the equations and referred from research paper SAE **J296.**

Bucket capacity (V) = Vs + Ve

Where Vs = Dump Capacity
Ve = Excess Capacity

$$V_s = P_{area} * \frac{W_f + W_r}{2} \quad \text{.........(1)}$$

$$V_e = \frac{L_b * W_f^2}{4} - \frac{W_f^3}{12}. \quad \text{.......... (2)}$$

P_{area}= 67836 mm^2 (measured from the Part modelled using Creo- Elements)

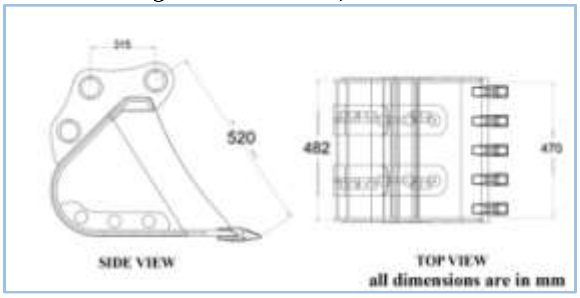

Fig.2 Bucket Dimension

Maximum open Length of Bucket = 490 mm
Inner width of bucket (Wf) = 470 mm
Thickness of bucket (t) = 6mm
Total width of bucket (Wr) = 482mm
Therefore
Dump Capacity of Bucket: V_s = .0323 m^3
Excess Capacity of Bucket: V_s = .019188 m^3
Total Bucket Capacity **V = .05 m^3**

D.Design of the Stick & Boom

Design is carried out for a load of 2000N. Therefore the initial breakout force of the Bucket is given by

$$\text{Max. Lift Capacity} = \frac{\text{Breakout force}}{(\text{Factor Of Safety} - 1)} \quad (3)$$

Factor of safety is taken According to Roymech, UK standards [7]as 5, (For materials that are to be used in uncertain environments or subject to uncertain stresses).

Breakout Force = Max.Lift Capacity * (FOS- 1) .... (4)

= 8000 N.

Bending Moment = Force X Distance …..(5)

Force is said to act at one end and the effort is at the other end since it is of type CLASS 1 Levers. Therefore

Length = Bending Moment / Breaking Force… (6)

Moment is Calculated Using Bending Moment equation

$$\frac{M}{I} = \frac{\sigma}{y} \quad \ldots\ldots (7)$$

Allowable Stress = Ultimate Strength/FOS ...... (8)

= 138 N/mm^2

Moment of Inertia is given by the formula from PSG DATA BOOK as.

$$I = \frac{bh^3 - b_1h_1^3}{12} \quad \ldots\ldots (9)$$

Assumptions:

* The stick cross section is idealized into Box Channel Cross Section of 100mm X 130 mm with thickness of 12mm.

* The BOOM cross section is idealized into C Channel Cross Section of 110mm X 155 mm with thickness of 12mm.

Using the above equations the

Length of Stick = 1700mm
Length of BOOM= 1970mm

E. Design of Banana Boom for Backhoe:

Banana boom as the name represent it is in the shape of the banana the ratios of the basic dimensions for the design of boom for backhoe are given below

Length: Height (L:h) = 2:1
Ratio of inclination height and Length is (a:L) = 1: 1.5
Angle of inclination of Boom is 30° to 50°
In this design it is taken as 45°

The length of the boom (L) is already calculated using bending moment equation as 1970mm

The following figure gives the idea about the representation of length and height

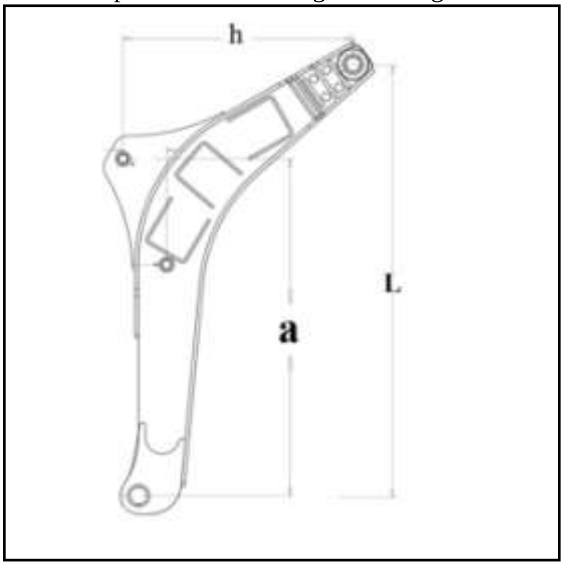

FIG .3 Length and Height of Banana Boom

Therefore

Height (h) = 985 mm
Inclination height (a) = 1313.13 mm
≈ 1310 mm

F. Hydraulic Pump

Pump Used:	Gear pump
Max.Pressure	= 250 bar
Operating Pressure	= 150 bar
Speed Range	= 700 rpm – 1500 rpm
Operating Speed	= 750 rpm
Horse power	= 50 hp

The main reason for using gear pump is it provides precise volumetric control of the fluid and creates more output force for the given input pressure.

G.Swing Design

The swing in backhoe is the component to turn the backhoe to its right and left. It is similar to a rocker arm provided with hydraulic force to turn the backhoe. It is positioned at the bottom of the BOOM to which the boom cylinder is attached.

It is created using modelling software with the backhoe boom assembly the hydraulic cylinders used to generate force are smaller in size when compared to other hydraulic cylinders. Two cylinders are used to swing it in either directions.

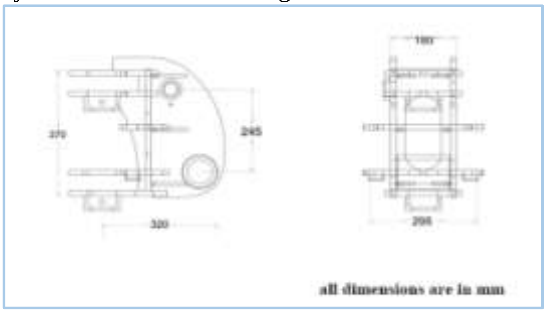

Fig.4 Swing Design

H.Hydraulic Cylinder and Piston

The stroke length of the piston is taken based on the angle of rotation that has to be achieved in the components Boom , Stick and the Bucket. For maximum storing capacity the bucket must have a rotation of 100° to 120°, the stick must have 120° to 135° angle of rotation and the boom is said to have a rotation of 55° to 70°. The stroke length of the hydraulic unit is calculated based on ratio with the angle of rotation of the individual parts. The provided standard ratios are

Boom Cylinder: Boom Rotation = 6:1
Stick Cylinder: Stick Rotation = 5: 1
Bucket Cylinder: Bucket Rotation = 4:1

Initially the angle of rotation of Boom, Stick and Bucket are taken as 60° 120°, and 100° respectively.

Table 2 Standard Hydraulic Cylinder and Piston Dimension

Component	Cylinder diameter (mm)	Piston Diameter Di(mm)	Rod diameter Dr(mm)	Cylinder length (mm)	Stroke Length (mm)
For BOOM	120	100	65	550	350
For STICK	120	100	55	800	600
For BUCKET	100	80	45	600	400
For SWING	100	80	60	400	300

TABLE.3 Hydraulic Cylinder and Piston Parameters

PARAMETERS	BOOM	STICK	BUCKET	SWING	STABILIZER
CYLINDER BLIND END AREA (mm^2)	7850	7850	5024	5024	7850
ROD AREA (mm^2)	3316.62	2374.625	1589.635	2956.63	3316.62
CYLINDER ROD END AREA(mm^2)	4533.38	5475.375	3434.375	2067.37	4533.38
CYLINDER OUTPUT FORCE (KN)	117.75	117.75	75.36	75.36	117.75

I. Position of Hydraulic Cylinder with Respect to Boom, and Stick

The free body diagram of the boom and stick contact is taken from "SAE J1179 standard "Hydraulic Excavator and Backhoe: Digging Forces" [9] is used to determine the location of the hydraulic cylinder and piston joints.

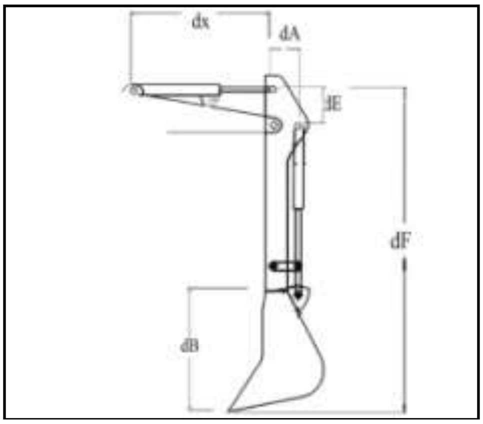

FIG.5 Free Body Diagram

Maximum angle between the boom inclination and cylinder is taken as 15 degree. Therefore

$$\tan \Theta = \frac{dE}{dx}$$

dE = 375 mm
and dA = π tan Θx dE
dA = 315.5mm
dF = total stick length + max.open width of Bucket
dF = 2220 mm
dB = 520 mm

Total span = BOOM length + dF - dE - dA
= 3499.5 mm

The backhoe is designed to cover a distance of 3500 mm from the tractor which is nearly 11.5 feet. The span of the backhoe is said to be 11 feet.

J.Bucket Curling Force and Digging Force

The bucket curling force is the force that is generated in the bucket tip by the movement of the stick to which the bucket is attached. While the digging force is generated by the bucket cylinder which controls the movement of the bucket. With SAE J1179 standard "Hydraulic Excavator and Backhoe: Digging Forces"[9] as reference bucket curling and digging forces are given by

$$\textbf{Bucket curling force} = \frac{P \times \pi \times D_A^2 \times dA \times dE}{4 \times dF \times dB} \quad ....(10)$$

$$\textbf{Bucket digging force} = \frac{P \times \pi \times D_B^2 \times dA}{4 \times dF} \quad ...(11)$$

Where

P – operating pressure, dA,dE,dF,dB are taken from the free body diagram, D_A is the diameter of the cylinder used for stick movement and D_B is the diameter of the cylinder used for the bucket movement.

Bucket curling force= 17.377 KN

Bucket digging force = 16.734 KN

H.Diameter of Pin

The pin length can be determined using the respective component width as it is made to fit inside the component.

The pin diameter is determined using the bending moment equation in equation no.7Where y= distance from the centre axis to the outside surface of pin i.e D/2. Factor of safety is taken According to Roymech, UK standards [7]"The FOS =4 Materials obtained for reputable suppliers to relevant standards operated in normal environments and subjected to loads and stresses that can be determined using checked calculations"

Here breakout force includes the component weight also which is taken from the ANSYS result.

Table.4Component Weight and Pin Dimensions

S.NO	Component	Weight	Total load (N)	Breakout force (N)	Length of pin (mm)	Diameter of pin (mm)
1	Bucket	19.8	2194.04	8776.16	170	40
2	Stick	48.2	2472.36	9889.44	175	45
3	Boom	60.31	2591.04	10364.15	200	50

V. DESIGN OF LOADER AND CHASIS

A.Loader Bucket:

Maximum open Length of Bucket = 490 mm
Inner width of bucket (Wf) = 1410 mm
Thickness of bucket (t) = 6mm
Total width of bucket (Wr) = 1422mm

Therefore

Dump Capacity of Bucket is calculated using the Equation 1

$$V_s = .0961\ m^3$$

Excess Capacity of Bucket is calculated using the Equation 2

$$V_s = .0808\ m^3$$

Total Bucket Capacity

$$V = Vs + Ve$$

$$\mathbf{V = .1769\ m^3}$$

The loader is designed for a load of 6000 N with the same open length as in Backhoe of 490mm.

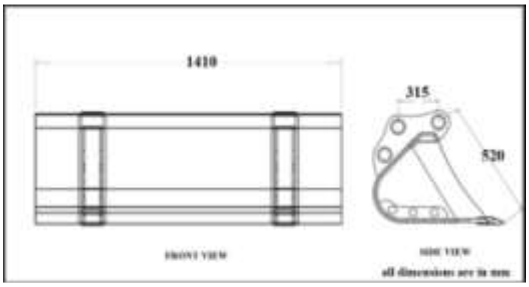

FIG.6 Loader Bucket Dimensions

The same dimension of hydraulic cylinders used for moving the backhoe stick is used here also for the bucket movement and boom movement.

BLoader Boom

In this design the stick and arm present in the normal loader is made in to a single boom with the ratio of 1:1 inclination height and Boom height.Similar to backhoe -boom design the section is idealized to cross section of C-Channel of 130mm x 130 mm with thickness of 12mm. There will be two booms present to lift the bucket at the same time so the breakout force is divided into two.

Breakout force for one arm = 12000 N

$I = 70.6X\ 10^5\ mm^4$

Moment is Calculated Using Bending Moment equation in eq.7 and eq.5.

M = 23.66 X 10^6 N-mm

Length = Moment / Breaking Force

L = 2140 mm

Length of the loader boom = 2140 mm.

The length to height ratio is 2:1 therefore the height of the boom is 1070mm from the base of the post.

Inclination height = 1070 mm

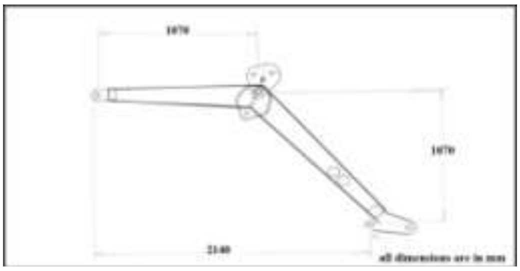

FIG.7Loader Boom Dimensions

C.Chassis Construction

The backhoe and loader designed are for small scale purposes with the agricultural tractor as the operating source which doesn't have a chassis. In normal tractor the engine and other components are mounted over the front and rear axle. So a simple chassis must be designed to lay a platform to mount these special attachments.

The wheel base of agricultural tractors differ with the manufactures here MAHINDRA Tractor 250 is considered which have front wheel clearance of 350mm. and wheel base of 2650mm in length.

Therefore the chassis must be in length greater than or equal to 1.5 times the wheel base.

With the trial and error method of modelling the finalized length of the chassis is 3900mm. The chassis is fitted to the front and rear axle of the tractor. For increasing the strength of the chassis a simple ladder shaped chassis is designed.

The cross section of the chassis is taken as BOX channel of 120mmX120mm with thickness of 12mm.

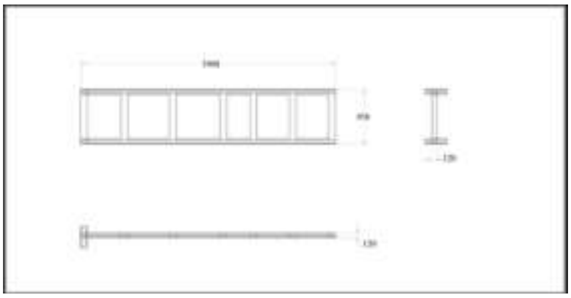

FIG.8Chassis Structure and Dimension

VI. 3D MODELLING AND ANALYSIS

The 3d modelling is carried out in creo parametric software of version 2.0. Which is also used for drafting. While the analysis is carried out using ANSYS-Workbench. Structural analysis is carried on the components in backhoe and loader to ensure that the components will withstand at the specified load.

A.Backhoe Bucket

The backhoe bucket is analysed for the designed load of 2000N at maximum loading condition. The load is applied in terms of force in Y-Direction acting downwards. Maximum developed stress = 6.5 N/mm^2

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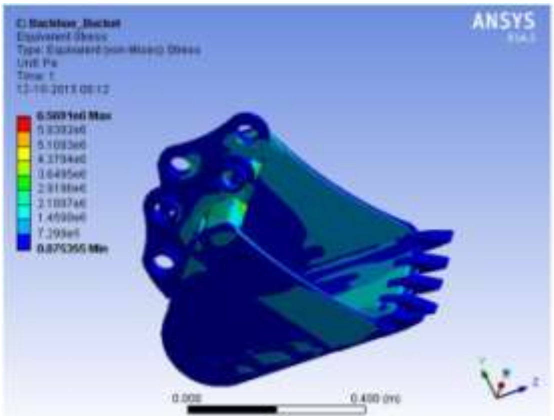

FIG.9 Equivalent Stress Analysis in Backhoe Bucket

B.Backhoe Stick

The stick is analysed for a load of 2500 N which includes the bucket weight which is determined during the analysis of the bucket. The end connected to the boom is fixed and the load is applied at the other end. The maximum developed stress is 35.7 N/mm^2.

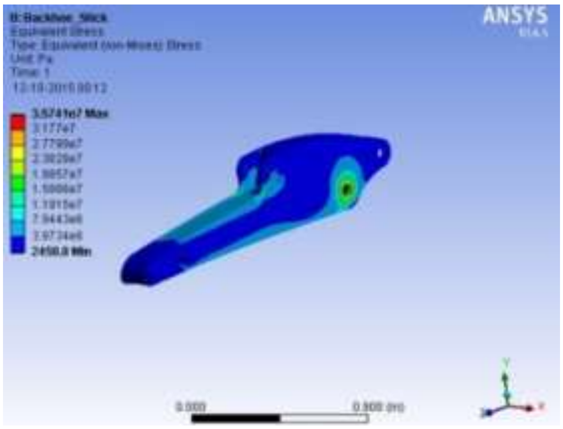

FIG .10Equivalent Stress Analysis in Backhoe Stick

C.Backhoe Boom

The stick is analysed for a load of 3200 N which includes the bucket weight and stick weight which is determined during the analysis of the bucket. The end connected to the swing is fixed and the load is applied at the end connected to the stick. The maximum developed stress is 8.03 N/mm^2

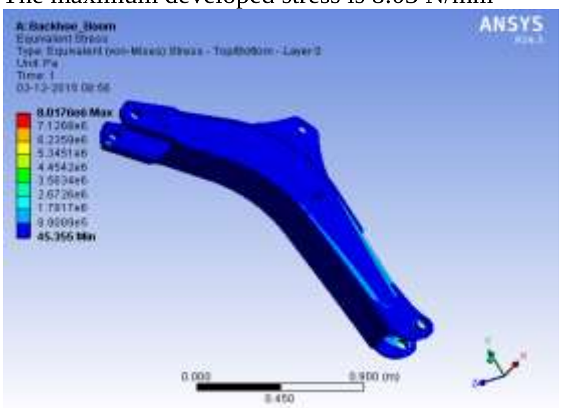

FIG .11Equivalent Stress Analysis in Backhoe Boom

D.Loader Bucket Analysis

The loader bucket is analysed for the designed load of 6000N at maximum loading condition. The load is applied in terms of force in Y-Direction acting downwards. Maximum developed stress = 8.9 N/mm^2.

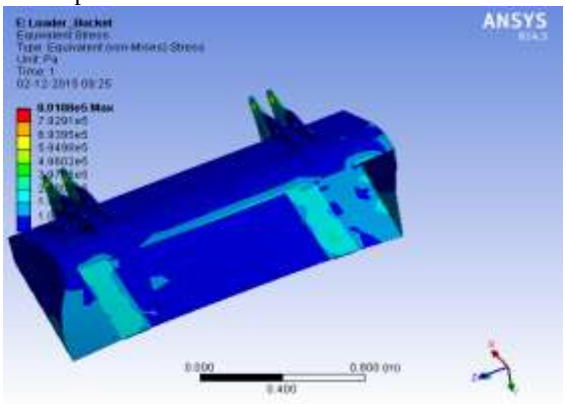

FIG.12Equivalent Stress Analysis in Loader Bucket

E.Loader Boom

Loader has two booms so the force is load is equally divided among the two booms. Therefore total load of 6800N including the bucket weight is applied equally on two boom end connected to the Bucket. The end connected to the post is fixed. The maximum stress 6.5 N/mm^2 is developed at the fixed end.

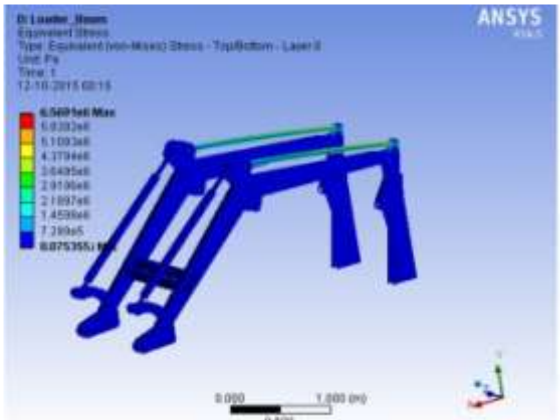

FIG .13Equivalent Stress Analysis in Loader Boom

F. Chassis

The chassis designed is analysed with the loading condition at two points and fixed support at two points. The fixed support is provided at the point where the chassis is connected to the wheel axle and the load is applied at the points where the backhoe and loader are placed. The load of 3400 N is applied at the backhoe portion and 7300 N is applied at the loader portion. The loads are applied including the self-weight of the loader and backhoe components.

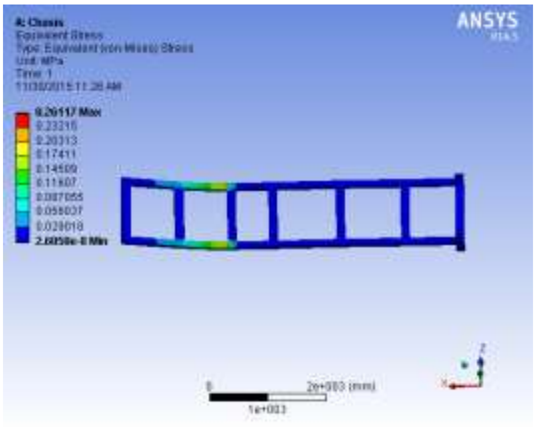

FIG.14Equivalent Stress Analysis in Chassis

H. PIN

The pin is the component which is subjected to tensile load at two points. In fig.15 bucket pin is analysed with both the ends fixed and the load of 2194N (design load + bucket Load) is equally applied at two points nearer to its fixed end. The maximum equivalent stress developed is 11.129 N/mm^2.

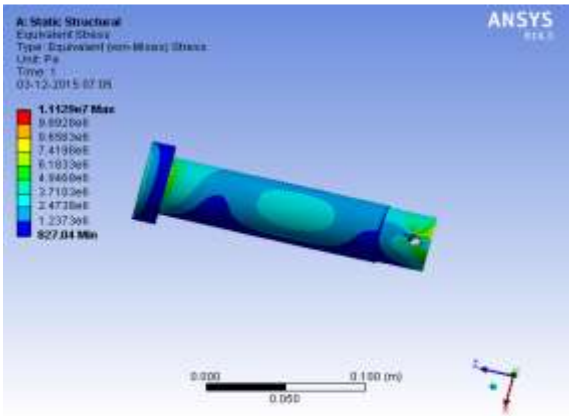

FIG.15Equivalent Stress Analysis in Pin

VII.CONCLUSION

In this design a detachable backhoe and loader components are designed to be fitted on a agricultural tractor to lift a load of 2000N and 6000N respectively. This attachment can be removed once its work is completed and the tractor can be used for other purposes like ploughing, carrying loads etc. This backhoe is preferred for trenching and digging in the fields where the trenching process will be carried out often and to carry waste from fields through the loader.

The detachable type backhoe components are designed using theoretical calculations and with modelling module using CREO PARAMETRIC. Here Finite Element Analysis using ANSYS WORKBENCH can be used as a tool to redesign the component without making the prototype and the loading condition can be simulated and make the necessary changes at the design level, if required for the proper functioning of the component this reduces the time consumption in making of a improvement to the existing design.

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