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Optimisation of the Boom of an Excavator

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ABSTRACT: Optimization in weight was achieved by modifying the cross-section of the current model keeping the sectional modulus at specified planes nearly constant. An iterative method was adopted for reaching the most optimum geometric model in terms of cost efficiency, weight reduction, manufacturability, and operation time. The proposed model was examined and verified for both **Digand Dump** load case.

KEYWORDS: excavator, boom, weight optimization, cost optimization, CAD, 90-90-90 condition, SN – diagram

I. INTRODUCTION

An excavator is heavy construction equipment, which is commonly used in construction work, mining work etc. According to off highway research about Equipment Analysis in India, excavator market is continuously growing. One of the parameters affecting the productivity of machine is the overall weight of the machine. A traditional design of boom results in poor efficiency and ultimately increases its working time. The boom is one of the heaviest structures of JS205LC excavator. Having studied the different types of beam cross-sections and shapes, and the pre-existing cross-section of the boom, we came to the conclusion of implementing the varying I-beam cross-section for the same. The benefits of our design against the old one were compared and verified through section modulus calculations, modelling (NX UniGraphics) and analysis (ANSYS). An iterative method was adapted during the design and analysis of the new geometry. During this development, a lot of factors were taken into consideration to reach an optimum value. A well balanced design with reduced weight and minimum increase of stress concentration from the original value were main priorities that were set beforehand.

Problem Statement: Better boom design in the excavation process has been always a challenging task for the engineers. The conventional design of a boom of an excavator has box cross section. The box cross-section is bulky and ends up increasing the weight of the excavator. We have tried to improve the current design of the boom to reduce the weight and optimize the design of the boom using different cross sections keeping the pivot points unchanged. Geometry was altered keeping sectional modulus constant at predefined sections.

Objectives: The objective of this project was to study different cross sections and design the boom with an optimized varying cross section and also to study about sectional modulus and its significance.

Parts of an excavator:

1. Bucket
2. Arm
3. Boom
4. Cabin
5. Hydraulics
6. Engine
7. Tracks
8. Counterweight

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II. LITERATURE REVIEW

Analysis and Optimization of Boom: In this paper, the weight of the boom was reduced by reducing the dimension of each plate and by trial and error method an optimized design was obtained.

FEA Analysis and Optimization of Boom of Excavator: An attempt was made in reduction of the weight of the boom by including trusses in the design. Material was removed from places where it was safe thereby reducing the weight.

Optimization of The Hydraulic Excavator Boom Using FEA Approach: The thickness of the material is reduced in the modelling for optimum weight of the excavator. The optimization is done with the varying thickness of the boom plate and lug plate thicknesses.

III. METHODOLOGY

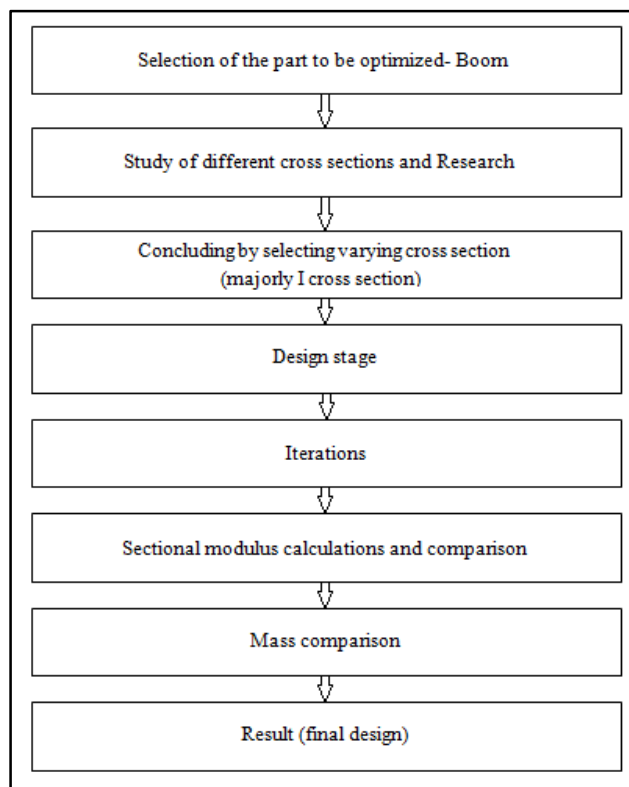


Table1: Flowchart of Methodology

3.1. Selection of part (boom)

The part which we chose to work on was the boom of an excavator. This was due to the following reasons:

- Considering reduction of weight as our main objective, boom being the most heaviest part in structures we chose to optimize boom
- Excavator consists of arm, bucket and boom. Boom is one of the changeable part

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- Bucket is interchangeable part with limited life span
- Boom should have maximum life span



I- section

Figure 1: I-section

I-Section is as showed in the figure. I-section is strongest in bending with reduction in weight of the structure. Hence we considered using I-section in our design. This makes the beam more economical and lighter. This was a major part of the design change that we inculcated within our revised model for the optimization of the boom. Major weight savings were achieved by selecting an I-cross section.

- Allows distributing load over a wider area.
- They weigh less than a square beam of the same size but can support a larger load making them more efficient and economic.

Design:Following design changes were included for modified boom -

Parts of a Current Boom	Parts of Proposed Boom
Top Wrapper (varying thickness)	Top Wrapper (reduced constant thickness)
Bottom Wrapper (varying thickness)	Bottom Wrapper (reduced constant thickness)
Baffle plate	I-section Plate at the centre
Side plates	Modified Side Plates
Pivoting points	Baffle Plate
	Pivoting points

Table2: Design Changes

Fatigue life:In material science, **fatigue** is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. Fatigue occurs when a material is subjected to repeat loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), interfaces of constituents in the case of composites, and grain interfaces in the case of metals. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will increase the fatigue strength of the structure.

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90-90-90 condition:

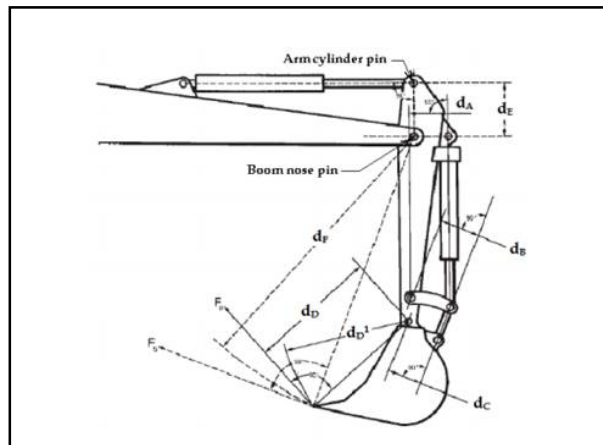


Figure 2: 90-90-90 condition

The 90-90-90 condition is considered for the worst case scenario for force application. This arrangement is explained below [1]:

- The angle between boom cylinder and the line joining the boom foot and boom cylinder pivot should be 90deg
- The angle between arm cylinder and the line joining the arm pivot and the arm cylinder pivot should be 90deg.
- The angle between bucket cylinder and the line joining the bucket pivot and bucket cylinder pivot should be 90deg.

Breakout force is the maximum force exerted on the tooth tip of the bucket during operation of an excavator. So the components are so designed to withstand this maximum force. A moment acts upon the boom as a result of this force. This maximum moment is the product of the breakout force and the perpendicular distance.

Loading cases:The three load cases which are to be considered while designing are:

- Dig: In this case the force exerted is maximum on the excavator compared to other cases. This case considers the digging action of the excavator on site. The bucket is in contact with the ground. The force exerted on the bucket transferred to other parts of the excavator
- Dump: The material which is dug by the excavator which is held in the bucket, is then unloaded at the required place or other machines. For example unloading of soil or mud by the excavator on the ground or in the machines. In this case the bucket is operated with the help of hydraulic cylinders due to which the unloading action takes place.
- Slew: In this case the links of the structures of an excavator that is the boom, arm and the bucket are moved along the pivots using hydraulic cylinders. This action helps in digging at one place and dumping at the other required place.

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IV. ITERATIONS

The current cross section of the boom is box has a single baffle plate at the centre. To optimize it we carried out the following iterations:

4.1. First iteration:

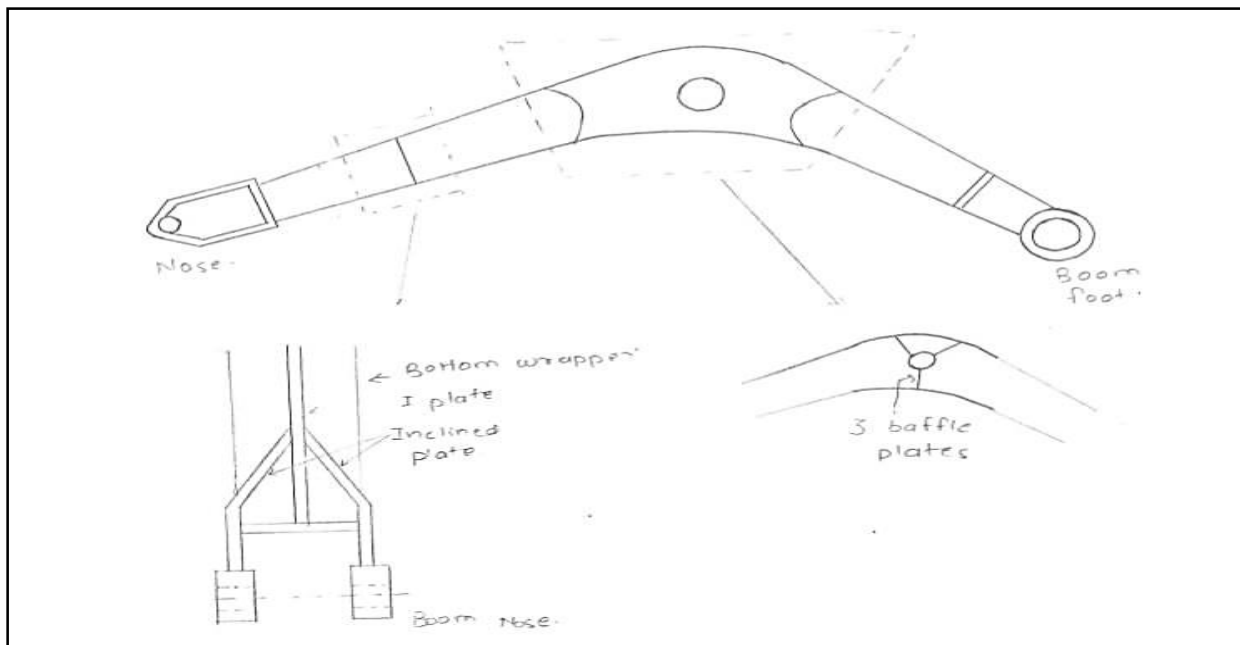


Figure 3a: Iteration 1 – Overview

- The box cross section was replaced by adding an I-cross section, by adding a plate having certain thickness through the entire length of the boom in the center and by eliminating side plates.
- Further, side plates were added in the middle of the boom.

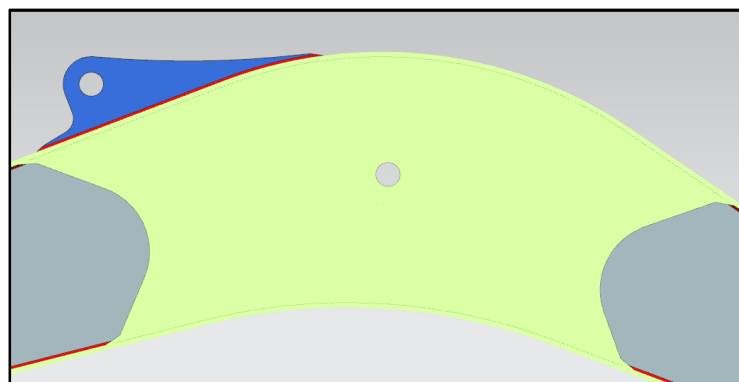


Figure 3b: Modified Side Plates

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- Two more baffles were added at the centre to increase support making it three baffles in total.

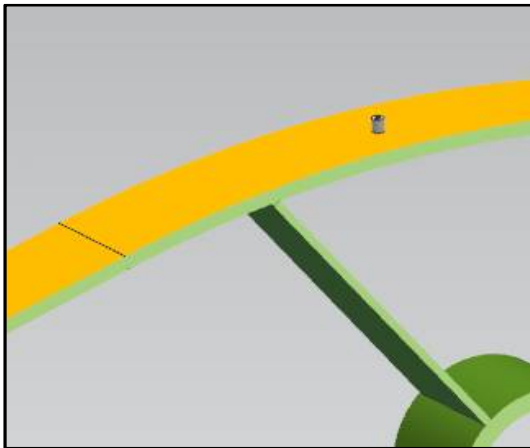


Figure 3c: Current Baffle Plates

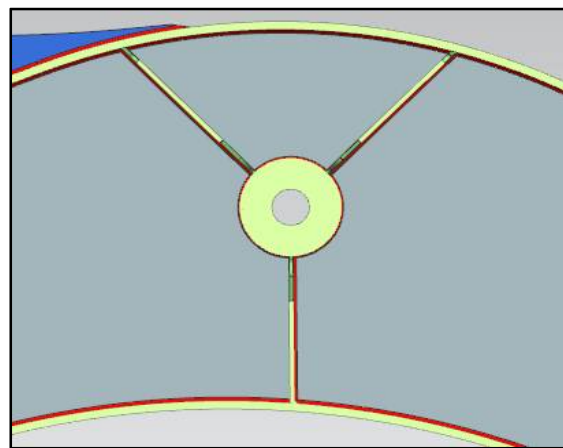


Figure 3d: Modified Baffle Plates

- These baffle plates were attached to the pivot to improve support and better distribution of stress.
- These plates played a significant role in design modifications, which we will see further.

4.2 Second iteration:

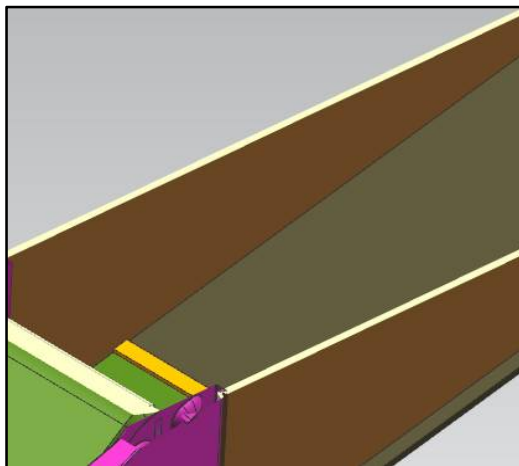


Figure 4a: Current Boom Nose Section

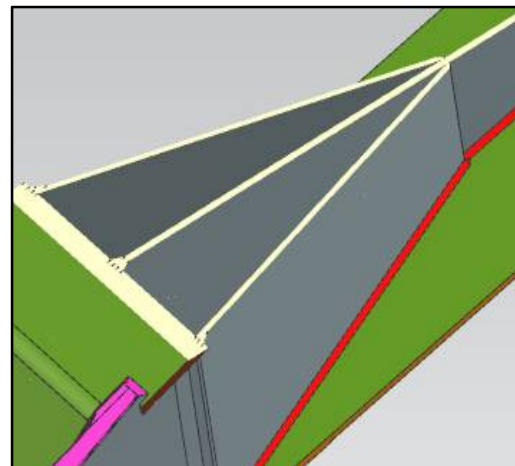


Figure 4b: Modified Boom Nose Section

- Inclined plates were added at the end of the length of the boom.
- The shape of the side plate was modified as shown in order to distribute the stresses evenly.

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1.1. Third iteration:

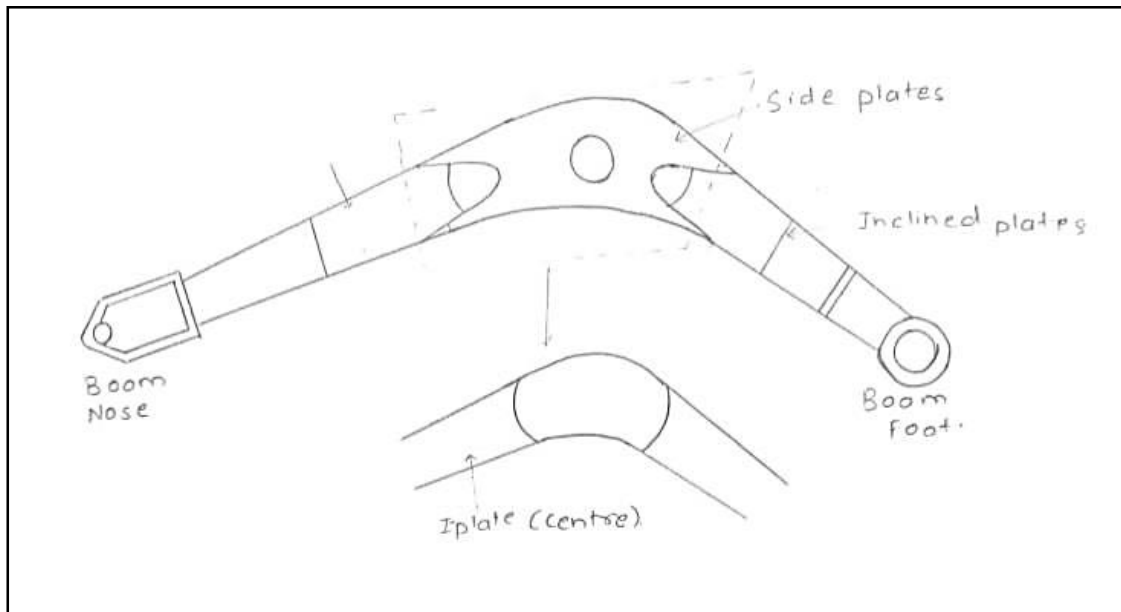


Figure 5a: Iteration 3 – Overview

- At the hard points where the inclined plates were added, the part of the I-section plate that was present in between the inclined plates was removed, to reduce weight.

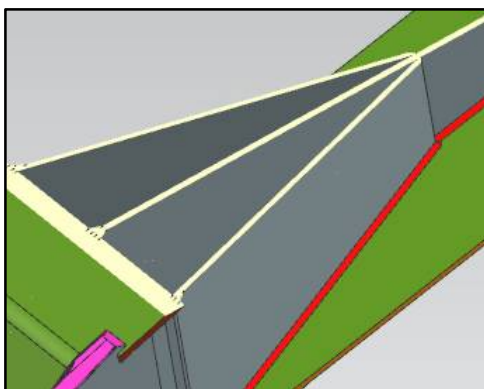


Figure 5b: Boom Nose Section

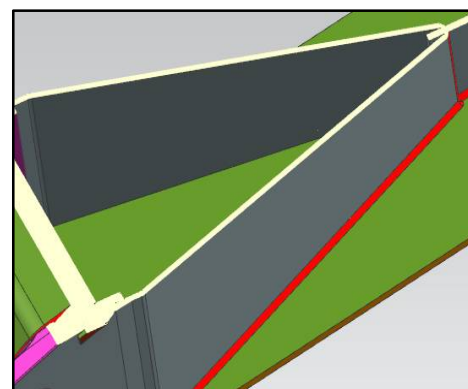


Figure 5c: Modified Boom Nose Section

- An extruding section of the I-section plate for making welding easier.
- No substantial changes were observed in the stress patterns.

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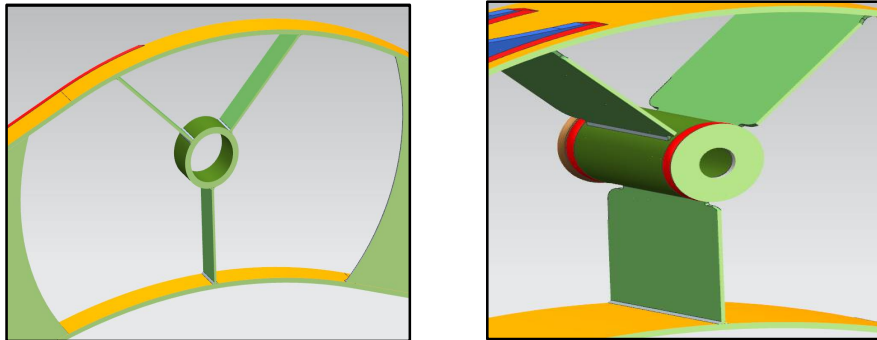


Figure 5d: Modified Cut-out I-Section

- At the center a circular cut was made in the I-section plate for optimizing further.

4.1.1 Clarification: Up to three iterations we were not being able to satisfy the dig and dump conditions. The stress concentration was distributed over a large surface.

4.2 Fourth iteration:

4.2.1 Causes of failure:

- Extreme localized stress concentration on top and bottom wrapper at side bent plates.

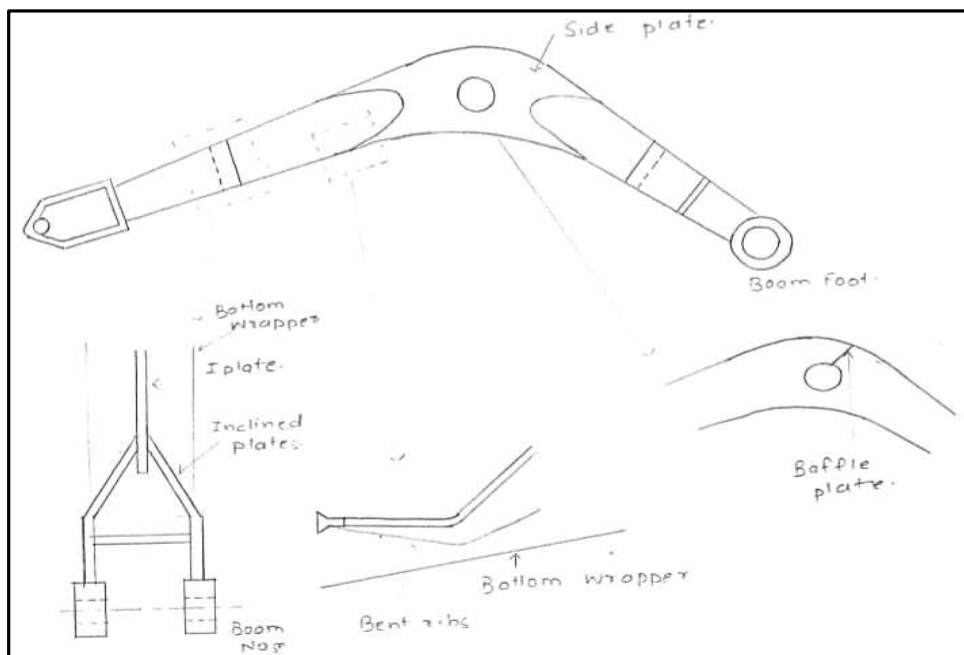


Figure 6a: Iteration 4 – Overview

- The thickness of the top and bottom wrappers was made uniform.

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- The ends of the side plates on either sides in the middle of the boom were bent inwards to even out the stresses.

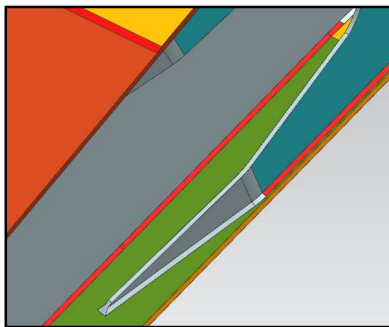


Figure 6b: Modified Side Plate

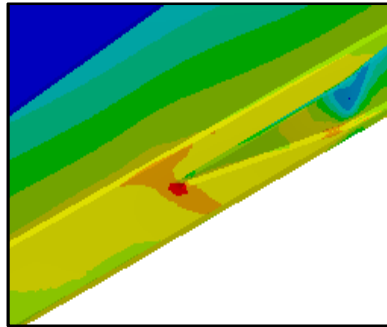


Figure 6c: Stresses for Dig Case [2]

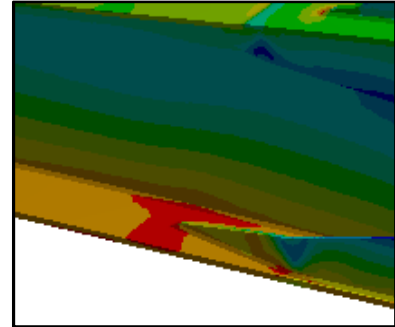


Figure 6d: Stresses for Dump Case

- The localized stress at the ends of the bent plates was observed to be significantly higher than the permissible value.
- The images denote stress patterns for dig and dump test cases.
- These results were unsatisfactory as extreme stresses could lead to rupture of the bottom wrapper, thus the model failed to dissipate stresses evenly.

4.3 Fifth iteration:

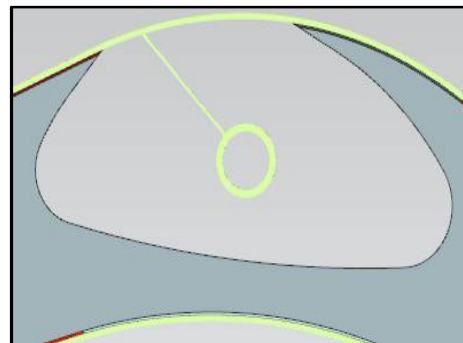
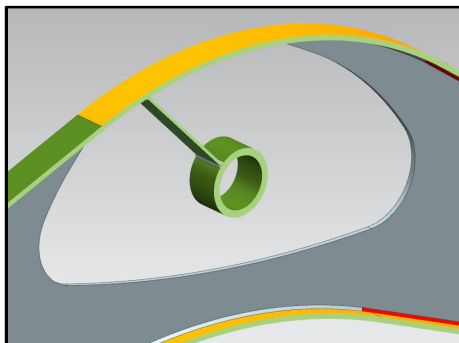


Figure 7: Modified Cutout I-Section

- The hole that was previously made at the center was improved as shown by keeping the lower portion of the I-section plate in the middle continuous.
- This was done to eliminate the stress concentration in the middle.

4.3.1 Causes of failure:

- It wasn't satisfying in dump case though the localized concentrated stress was eliminated.
- More rigidity was required for strengthening the model for dump load case. This meant adding more material, which lead to increased mass.

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4.4 Sixth iteration:

- The thickness of the middle plate was increased to increase the strength.
- Weld supports were added at the ends of the bent side plates to eliminate the stresses

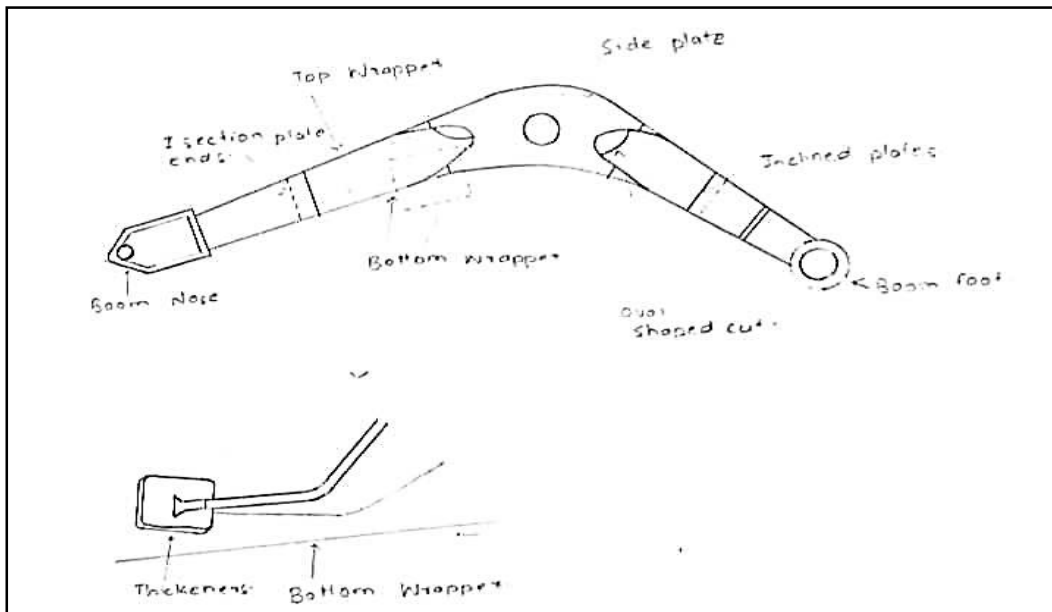


Figure 8a: Iteration 6 – Overview

- The middle plate deflected more than the allowable deflection. As a remedy, thickness was increased which in turn increased weight but made the model more rigid and strong.

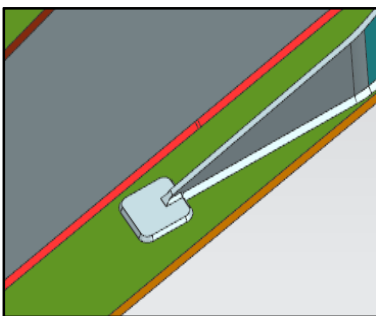


Figure 8b: Stress Reduction Plates

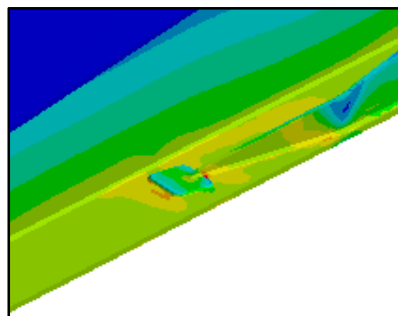


Figure 8c: Stresses for Dig Case

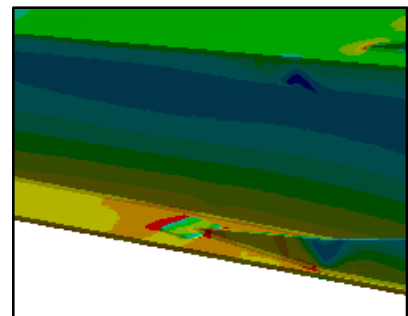


Figure 8d: Stresses for Dump Case

- The addition of a stress reduction plate enabled better stress dissipation due to an increased surface area. The stress concentration nearly vanished and satisfactory results were obtained.

4.4.1 Advantages:

- Results were satisfying in both dig and dump cases compared to previous iterations.
- The stress reduction plate was a useful addition as compared to the increase in weight.

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Sectional Modulus

Section modulus is a geometric property for a given cross-section used in the design of beams or flexural members. The elastic **section modulus** is defined as $Z = I / y$, where I is the second moment of area (or moment of inertia) and y is the distance from the neutral axis to any given fibre. It is often reported using $y = c$, where c is the distance from the neutral axis to the most extreme fibre. Sectional modulus was calculated at the seven predefined sections and the percentage change with respect to the current boom is given below in table:

Sections	A-A	B-B	C-C	D-D	E-E	F-F	G-G
Percentage change	25.416	17.4322	1.5922	0.76	26.9057	32.1199	9.7459

Table 3: Percentage change in Sectional Modulus

V. MANUFACTURING

The top and bottom wrappers, the middle plate, side plates, thickeners, baffles and inclined plates have to be laser cut. The top and bottom wrappers along with side plates are bent using bending machine. Boom nose, boom foot and boom pivot are casted.

Material of the boom: The material widely used for the manufacturing of the boom is structural steel having yield strength of 355N/mm^2 and ultimate strength of 450N/mm^2 . The minimum factor of safety considered while designing is 1.5

Assembly:

- The bottom wrapper along with the boom foot and boom nose is placed in position.
- The middle plate is welded on the bottom wrapper using fixtures.
- The inclined plates are welded at the boom foot and the boom nose.
- The right hand side plates along with the baffle plate and boom pivot are welded to the bottom wrapper.
- The left hand side plate is welded to the bottom wrapper boom pivot and baffle plate.
- The top wrapper is then placed and welded, enclosing the close structure.

VI. CONCLUSIONS

- A varying cross section over the length of boom replaced the box cross section.
- A total weight reduction of **121kgs** was obtained i.e. the initial weight of 1584kgs was reduced to 1463kgs.
- Overall stress concentration on the top and bottom wrappers of the boom was reduced as much as possible.
- Total number of welds for fabrication has decreased.
- Sectional modulus was almost same at every section.

VII. RESULTS

The proposed design of the boom was giving satisfactory results in dig and dump load cases along with the advantage of a mass reduction of **8.2%**, but was weaker in slew loading condition. The Sectional modulus calculated at various sections throughout the length of the proposed boom was almost equal with sectional modulus taken at the same sections on the original boom. It has a slight average deviation of about **16.28%**. Although the sectional modulus was lower at few sections, the design was analysed, tested and verified for dig and dump loading conditions.

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