FEA and Optimization of Elevator Bucket

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Abstract— Bucket elevators are the most widely used systems to transport bulk, dry, wet and liquid materials vertically. It is designed with various options of height, capacity, speed and constructive details depending on the type of transported material. The effective use of different type of bucket elevators completely depends on its design and type of bulk material. The trend is toward highly standardized units. In this paper practical application is considered; bucket elevator is selected and analysis is carried out. Based on analysis results, topology design is suggested and re-iteration is carried to prove its safety. In this optimization approximately 36% weight reduction is achieved.

Index Terms—Bucket Elevator, Analysis, Optimization.

I. INTRODUCTION

Bulk material handling is an engineering field of design of equipment used for the handling of materials such as ores, coal, cereals, grains, sand, gravel and stone etc. in loose bulk form. Bulk materials handling systems quite often require the lifting of bulk materials to other parts of the plant or process. Various technologies and equipment are currently available to the designer and practitioner. Generally they are classified in to three main categories.

1. Pneumatic conveyor or air lifter.
2. Conventional screw conveyor.
3. Bucket elevator.

Bucket Elevators are powered equipment consisting of an endless belt, or chain to which metallic or non-metallic buckets are fixed for conveying bulk materials in a steep or vertical or steep inclined path. Buckets attached to flexible belt/chain move unidirectional within a casing. Bulk materials is collected at bottom end of the elevator and delivered at the top end [1]. Bucket elevators are the simplest and most dependable units for making vertical lifts. Bucket elevator is ideally used where the product needs to be elevated and consume only a small amount of ground area. Variety of bulk materials from heavy to light and from large lumps to fine powder can be elevated [2]. They are a well-proven and reliable piece of equipment. Bucket elevator are available in a wide range of capacities and may operate in totally enclosed or entirely open area.

Bucket elevators operate by using an endless belt or chain on which buckets are mounted. The belt or chain revolves between two pulleys (one at top and one at bottom) and the buckets move with it. Buckets pick up product fed at the bottom of elevator and discharge at top as the bucket turns downward over the head pulley.

In mechanized bulk material handling industry bucket elevator has evolved as advanced material handling equipment. The effective use of different type of bucket elevators depends on design and type of bulk material. The trend is toward highly standardized units, but for high capacities and special material it is wise to use specially engineered bucket elevator. Main variations are in bucket thickness, casing thickness, drive equipment, and belt or chain quality. The major components of belt bucket elevator are drive head and bottom head, buckets, inlet and outlet, casing, drive unit, take up.

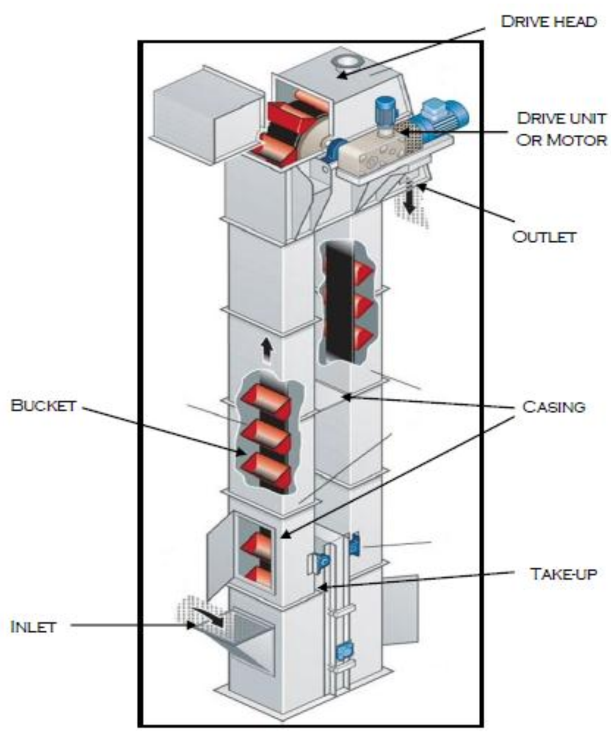


Fig 1. Parts of bucket elevator

II. CLASSIFICATION OF BUCKET ELEVATOR

Bucket elevators are mainly classified in following two types.

1. Continuous bucket elevator.
2. Centrifugal bucket elevator.

Many types of bucket elevators are available and each is different from other according to their application, feature, and design. The major classifications of bucket elevators are shown in fig 2.

The bucket elevator is generally used in chemical industry, building materials, ports and terminal, grain mine, pulp and paper industries, food, fodder, medicine related application and plastic. Cement factories, Power plant, Food industry etc.

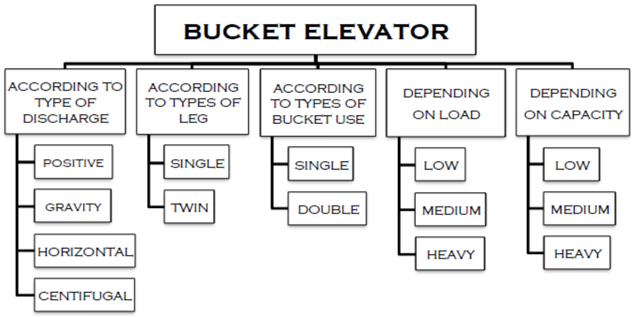
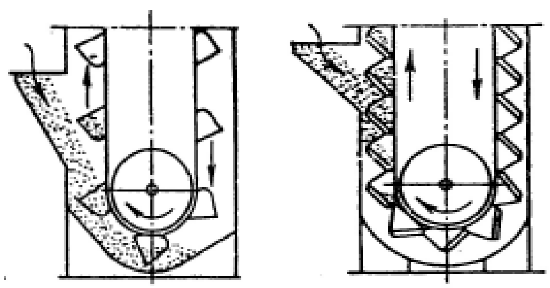


Fig 2. Classification of bucket elevator



a) Centrifugal b) Continuous

Fig 3. Types of buckets

III. PROJECT OBJECTIVE

1. Modeling and analysis of elevator bucket.
2. To optimize the existing model to reduce weight by topology optimization.

IV. SELECTION OF ELEVATOR BUCKET FOR APPLICATION

In a food industry there are multiple grains and other materials that are required like wheat, corn, sugar salt etc. Bucket elevators are used to transport grains and other ingredients from ground floor to required silo or storage area. Bucket elevator selection guidelines are given by IS standards listed in reference 7, 8 and 9. The general formula for calculation of the capacity of all types of elevator is as follows:

$$Q = \frac{F \times C \times W \times 3600 \times V \times 0.0001}{100 \times S} \quad (1)$$

Where,
Q = capacity of bucket elevator in tonn/hr;
F = constant, representing percentage filling of the buckets;
C = capacity of individual bucket in lit;
W= material bulk density in kg/m3;
V = belt or chain speed in m/sec; and
S = bucket spacing in m.

From above equation (1) it is clear that the bucket elevator capacity depends on the capacity of individual bucket, material bulk density, belt or chain speed, and bucket spacing. So keeping the capacity of individual bucket (i.e. bucket dimensions), belt or chain speed and bucket spacing constant, the bucket elevator capacity can be varied by varying the bulk material density i.e. changing the material conveyed.

Based on this we can design the bucket elevator in food industry for one grain and use it for other grain transfer as well. Now for which grain the bucket elevator to be designed for? If we design for higher bulk density material and use it for lower density bulk material the volume of the lower bulk density material conveyed will be less. The bucket selected will be underutilized. Whereas if we design for lower bulk density material and use it for higher density material the volume of the higher bulk density material conveyed will be higher. Application in food industry is considered where following grains and ingredients are required to be transported.

Wheat: – 640-720 kg/m3
Sugar: – 800-880 kg/m3

Quantity of wheat required is large compared to quantity of sugar. Let say if 200 kg of wheat is required then only 50 kg of sugar is required. If we design the bucket for sugar and convey wheat then the volume of wheat conveyed will be less. Also the bucket will be selected for higher load and will be underutilized for wheat. So to better utilize the bucket, it need to be selected based on wheat and then checked for carrying sugar.

The following factors bucket elevator selection for considered application:

Material for lifting: Wheat
Average bulk density of wheat (ρ): 640 Kg/m3
Capacity (Q): 30.00 Tonn/hour

Based on this selected bucket parameters are:
Length: 310mm
Depth: 170mm
Projection: 160mm
Bucket thickness: 1.9 mm

Selected bucket is analyzed considering the load conditions for conveying wheat. Then bucket is analyzed considering the load conditions for conveying higher bulk density that is sugar. Based on the analysis results design changes are proposed to optimize the bucket.

V. EXISTING BUCKET ANALYSIS

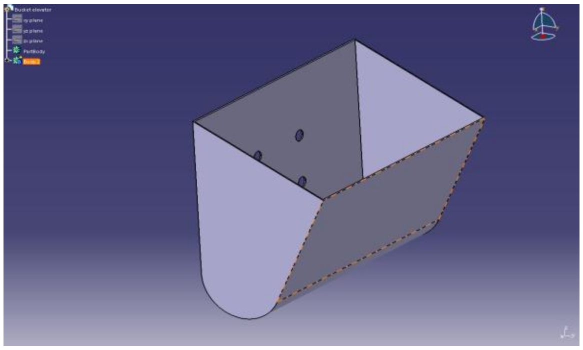


Fig 4. Elevator bucket CAD model view

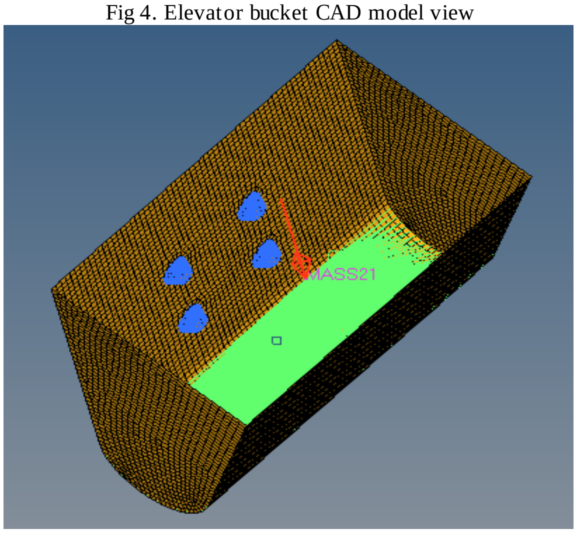


Fig 5. Constraint and forces applied in Hypermesh

Number of nodes: 8251
Number of elements: 8156
Element size = 2 mm

Table 1. Material Properties

Young's modulus	210 GPa
Poisson's ratio	0.3
Density	7860 kg/m³
Yield strength	250 MPa
Ultimate tensile strength	390 MPa

A. FEA analysis of elevator bucket for Wheat

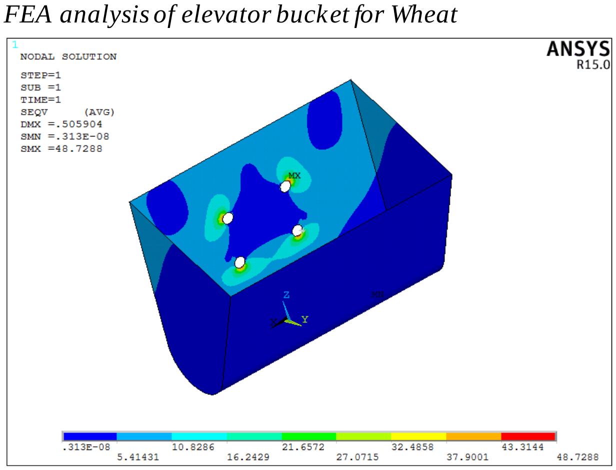


Fig 6. Von Mises stress for bucket elevator-Wheat

Stress value for bucket elevator is 48.72 N/mm^2 which is well below the critical value and deformation for bucket elevator is 0.505 mm. Hence, design is safe.

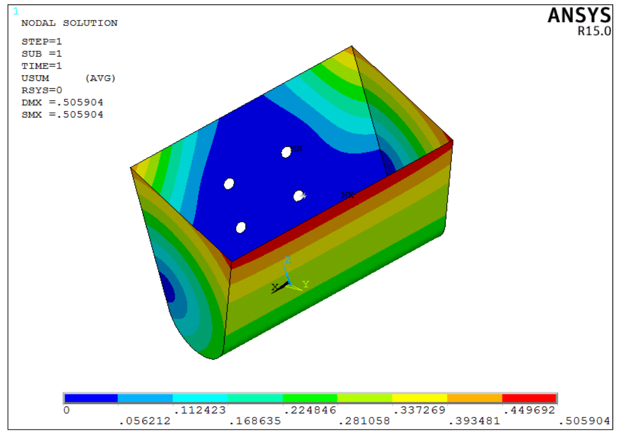


Fig 7. Displacement result for bucket elevator-Wheat

B. FEA analysis of bucket elevator using for Sugar

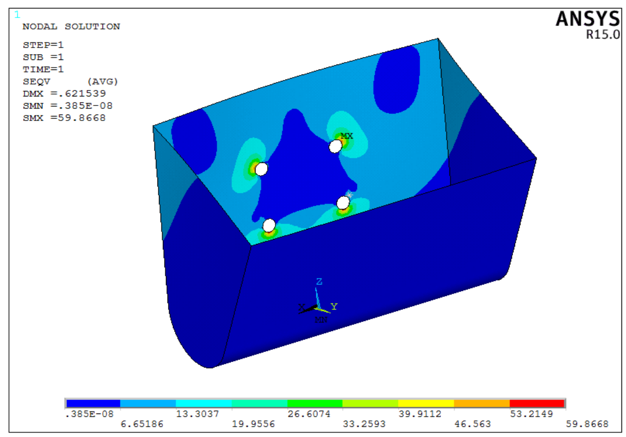


Fig 8. Von mises stress for bucket elevator-Sugar

Stress value for bucket elevator is 59.86 N/mm^2 which is well below the critical value and deformation for bucket elevator is 0.621 mm. Hence, design is safe. As stresses are well below the critical value, there's a scope for reducing the thickness and proceed further optimization by iterations.

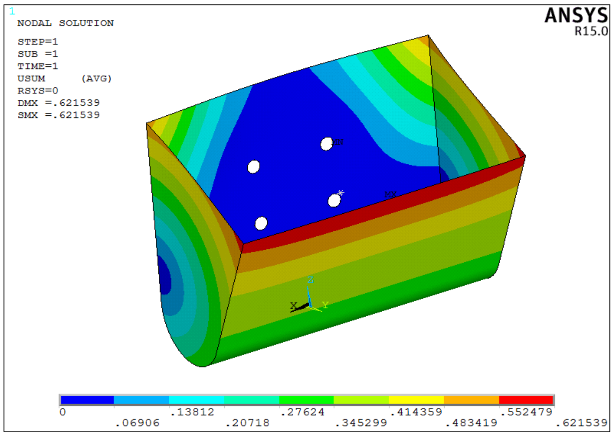


Fig 9. Displacement result for bucket elevator-Sugar

VI. OPTIMIZATION

From the existing bucket analysis it is clear that the stress value are very low compared to the allowable stress and there is scope for optimization. The maximum stress value is observed at the area where the bucket is connected to the belt or chain.

Topology optimization is a mathematical approach that optimizes material layout within a given design space, for a given set of loads and boundary conditions such that the resulting layout meets a prescribed set of performance targets. Topology optimization is used to find best concept design that meets the design requirements. Topology optimization is used at the concept level of the design process to arrive at a conceptual design proposal that is then fine-tuned for performance and manufacturability. Topology has more to do with the distribution of material, creation of holes, ribs or stiffeners, creation or deletion of elements in the structure.

So in exiting bucket using topology optimization the material is distributed by removing material in low stress region i.e. reducing the thickness of bucket. Iterations are carried out by reducing bucket thickness.

A. Iteration 1: By changing the thickness of bucket to 1.5mm.

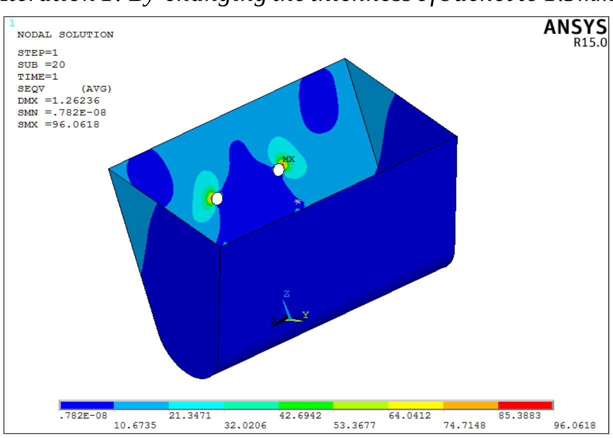


Fig 10. Von mises stress for bucket elevator-Iteration1

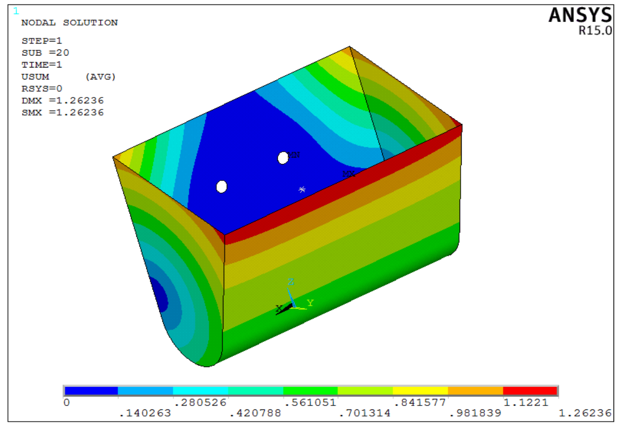


Fig 11. Displacement result for bucket elevator-Iteration1

Stress value for bucket elevator is 96.06 N/mm^2 which is well below the critical value and deformation for bucket elevator is 1.26 mm. Hence, design is safe. As stresses are well below the critical value, there is a scope for reducing the thickness and check for stresses.

B. Iteration 2: By changing the thickness of bucket to 1.2mm.

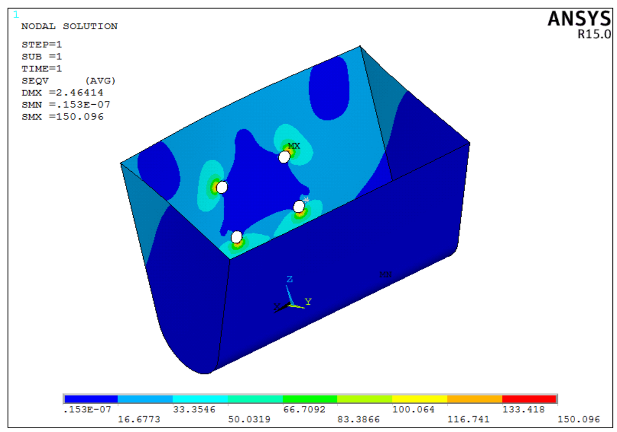


Fig 12. Von mises stress for bucket elevator-Iteration2

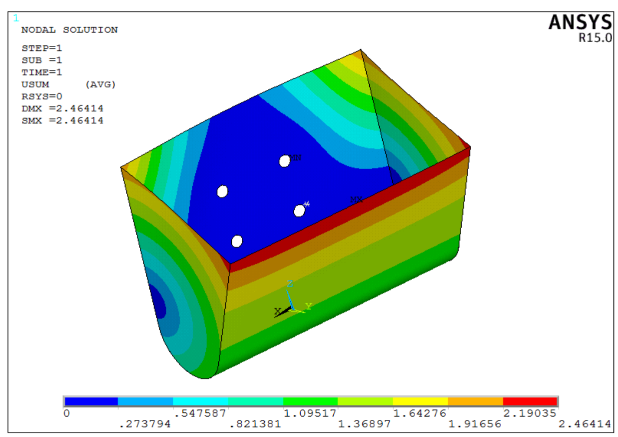


Fig 13. Displacement result for bucket elevator-Iteration2

Stress value for bucket elevator is 150.096N/mm^2 which is well below the critical value and deformation for bucket elevator is 2.46 mm. Hence, design is safe.

Sheet metal welding below 1.2 mm thickness is difficult. Also a safety factor of 2 approximately is achieved with 1.2 mm thickness bucket.

C. Iteration 3: By providing the stiffeners on the lateral sides of the bucket

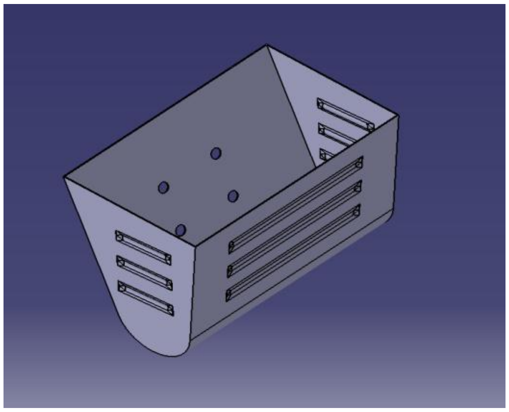


Fig 14. CAD model for iteration 3

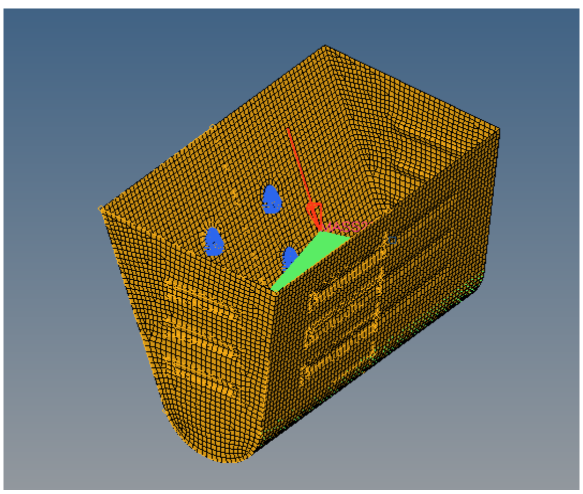


Fig 15. Meshed model for iteration 3

Number of nodes: 8474
Number of elements: 8376

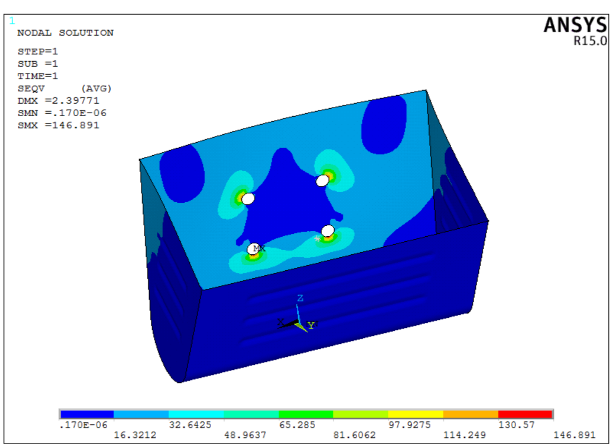


Fig 16. Von mises stress for bucket elevator-Iteration3

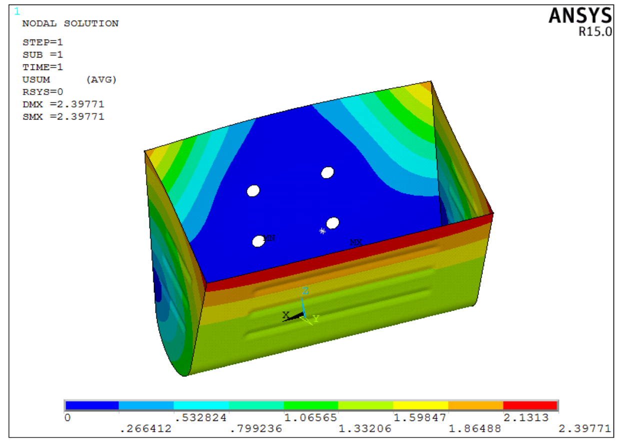


Fig 17. Displacement result for bucket elevator-Iteration3

Stress value for bucket elevator is 146.89 N/mm^2 which is well below the critical value and deformation for bucket elevator is 2.39 mm. Hence, design is safe.

VII. RESULTS AND DISCUSSIONS (FEA)

The existing model is analyzed for wheat material and then the analysis is carried out for denser material as sugar. The existing model is optimized by iterations so as to converge towards the optimum results by considering the sugar filled bucket elevator. The maximum stress value for optimized bucket elevator is 146.89 N/mm^2. The critical yield value of the material is 290Mpa. From the results, the stresses are well below the critical value. The final optimized model is capable of handling the loading conditions under the safety limits.

Deformation for optimized bucket elevator is 2.39 mm. As the bucket is made up of 1.2mm sheets the deformation occurred here is the nonlinear behavior of the geometry and hence the deflection does not indicate the plastic yielding. As the stresses are within safety limit, it clearly shows that the deflections are under permissible range.

Table 2: Weight reduction

Case	Weight (kg)
Existing Bucket (1.9 mm)	2.963
Iteration 1 Bucket (1.5 mm)	2.34
Iteration 2 Bucket (1.2 mm)	1.88
Iteration 3 Bucket (1.2 mm)(with stiffeners)	1.88

Weight Reduction = (Existing - Optimized) / Existing
= (2.963 - 1.88)/2.96
= 36.5 %

VIII. CONCLUSIONS

FEA and Topology optimization techniques can be effectively used for effective performance of bucket elevators and weight reduction. Use of 1.2 mm thickness elevator bucket along with stiffeners has shown positive results i.e. stress and deflections obtained are within permissible range.

With the modified design after topology optimization, weight reduction of approximately 36% is achieved in bucket material.

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