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and
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# Modelling of dragline boom structure

*Draglines are the one of the most significant and biggest equipment used in the opencast mines and civil engineering works for the removal of overburden. Despite being very costly, they remain an integral part of the mines for almost 100 years due to their low overburden removal cost per tonne of coal. Their ability to excavate very deep down the earth makes them very effective and important in the mining industry. They can dig up to 450 tons of material in a single cycle. During a typical dragline cycle machine undergoes various types of motion and experiences static as well as dynamic load on its front end assembly parts which may lead to the failure of such components if not properly maintained on a regular basis. In the current research paper, a dragline boom model is created and analysed for stresses acting on it during static conditions by performing finite element analysis in SolidWorks simulation software. Afteranalyzing stresses, their locations are studied. Based on the simulation results the overall structural behaviour of the dragline boom can be predicted.*

***Keywords:*** *Dragline boom, boom foot weldment, boom point, static conditions, finite element method (FEM).*

### Introduction

The dragline was invented in 1904 by John W. Page (as a partner of the firm Page and Schnabel contracting) for use in digging the Chicago Canal. The Marion, power shovel company, built its first walking dragline in 1939. Its largest dragline was the 8950 with a 150-cubic yard bucket and a 310-foot boom weighing 7300 tonnes. Later in 1997 Bucyrus acquired Marion company and became one of the giant manufacturers of draglines all over the world. Today P&H, Bucyrus and Caterpillar are the main manufacturers of draglines [1]. The only manufacturer of dragline in India is Heavy Engineering Corporation (HEC).

Dragline is a very expensive heavy equipment that cost approximately INR 500 crores and a commissioning time of about two years. It comes with various sizes of buckets (ranging from 20-120 cubic meters) and boom lengths (ranging from 45 to 110 meters) and may have weight more than 4000 tonnes. It can move more than 450 tonnes of material in a single cycle. A typical dragline cycle involves positioning of bucket above the material to be excavated, lowering the bucket and dragging it towards machine by means of dragropes to dig the material. After filling the material, bucket is hoisted with the help of hoist ropes and then a swing motion is provided to dump the material at a certain location. Fig.1 shows a typical dragline with all the parts.

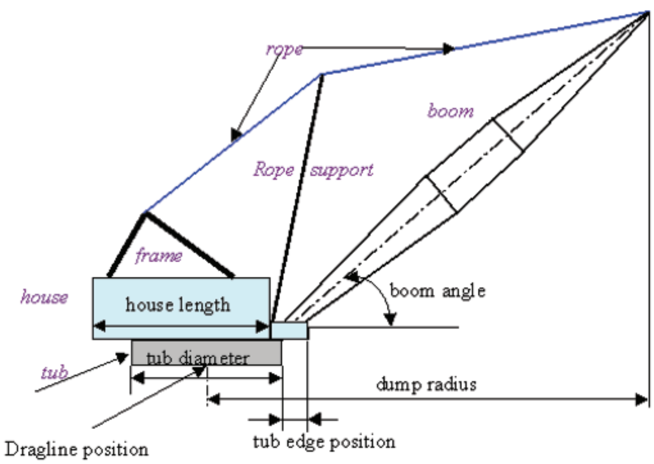


Fig.1 Basic diagram of dragline

The limitations of draglines are their boom height and boom length, which limits where the dragline can dump the waste material. Another limitation is their dig depth, which is limited by the length of rope the dragline can utilise. Draglines can only excavate a maximum of 50 to 80 m of overburden due to reach and dump height limitations [2]. A dragline is most efficient excavating material below the level of their base. Although a dragline can dig above it, it does so inefficiently and is not suitable to load piled up material (as a rope shovel or wheel loader can).

Despite the above limitations and their extremely high initial investment, draglines remain an integral part of many mines, due to their reliability, and extremely low waste removal cost.

As being very costly equipment, it is highly undesirable

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for the industry that machines undergo any sort of major failure. The components such as boom along with boom foot, boom point sheave and suspension point attachments suffer a major loading and unloading cycles. It causes them to develop cracks in these components at various locations which ultimately lead to the complete failure of components if not properly cared and maintained. Although scheduled maintenance of these components is performed on a daily or weekly basis yet these failures seem to happen over a certain period of time. One of the recent failures in the Indian mining industry was the collapse of dragline boom in a large mine.

In the current study, the dragline boom is considered to determine how the overall structure behaves during static loading conditions and the critical sections are observed.

Fig.2 Draglineboom collapse in a large mine, India

## Literature review

For almost 100 years since the introduction of draglines in mining industries the design of the machine remains the same and does not adopt any major change due to lack of research in this area. But in recent years various researchers started performing some work. In this area as a result of it some small changes in dragline components design can be seen if we compare them with the draglines of the 20th century. Some of the research works and their findings are summarised below as the part of my research work.

P. Dayswana has performed a lot of work in the field of dragline boom fracture. He performed a rigorous study over dragline booms and suggests the crack formation in the welding joint is the main cause of boom failure. He considered BE boom models of dragline with three main chords [3].

S. Frimpong, D. Ph, and N. Demirel has performed kinematic and dynamic simulation on dragline front end assembly. He considered the dragline front end assembly as a linear mechanism and performed simulations .forces on the boom point, and various locations were obtained as a result. Based on the results obtained he performed dynamic simulation and stress modelling [4].

Suraj Joshi et al suggested hot spot stress method to compute fatigue loading in heavily welded tubular joints. He concluded that high stresses occurred at weld toes in clusters and the main cause of failure is the failure of welds at joint. He also concluded that the hot spot stress approach could not explain the failure of the main chord [5].

Ying Li created a three-dimensional model (3D) dynamic dragline models for investigating the dynamic dragline performance and front end structural strength. The mechanical model was modelled as a rigid multibody system to cover all the dynamic and kinematic aspects of a dragline. He suggested a method for predicting the fatigue life of the dragline boom structures [6].

Fidels R. Mashiri predicted service loads in dragline tubular structures. He considered a case study of cluster a5. He installed various strain gauges on the 4 lacing cluster during the dragline operations and carried out tests for machine swing and digging. He concluded that welding is an important parameter in prediction of fatigue life of dragline clusters. The location of cracking was observed [7]

## Methodology

### Finite element method

The finite element method (FEM), sometimes also referred to as finite element analysis (FEA), is a numerical technique used to obtain approximate solutions of boundary value problems in engineering. In context of FEA a boundary value problem is a mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain. Boundary value problems are also sometimes called field problems. The field is the domain of interest and most often represents a physical structure. The field variables are the dependent variables of interest governed by the differential equation. The boundary conditions are the specified values of the field variables (or related variables such as derivatives) on the boundaries of the field. Depending on the type of physical problem being analyzed, the field variables may include physical displacement,

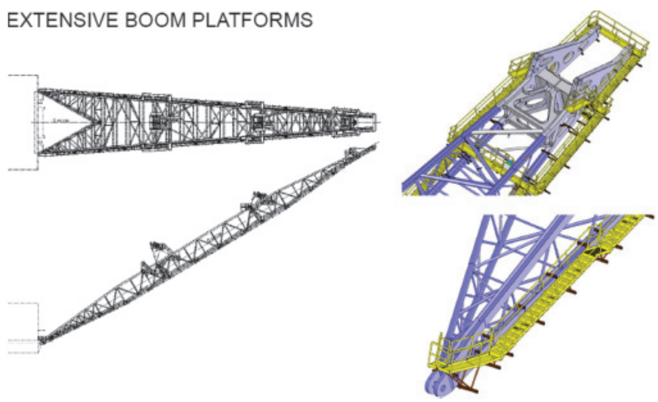


Fig.3 Schematic diagram of a boom structure. (9)

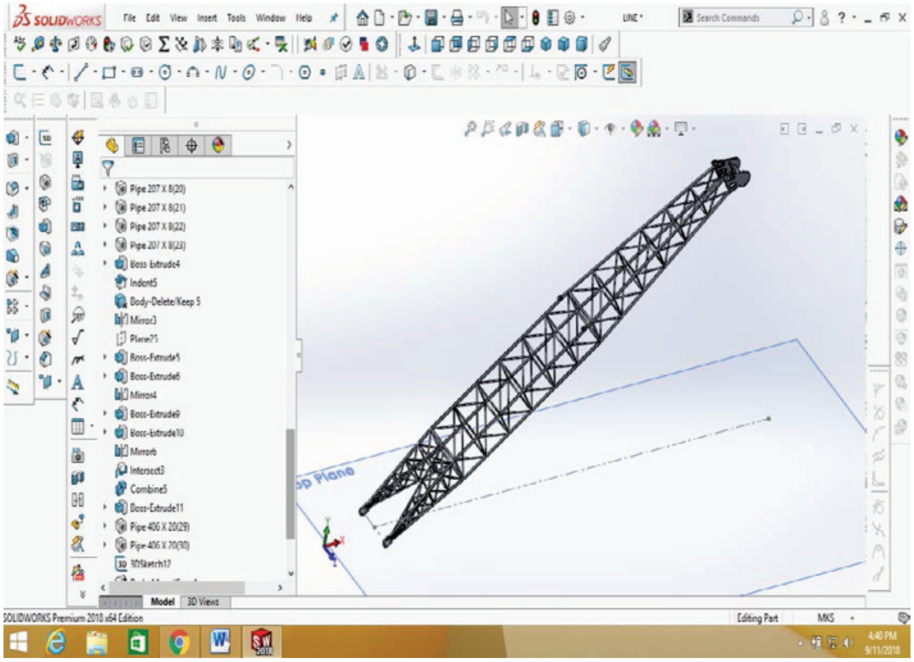

Fig.4 Dragline boom model created in Solidworks

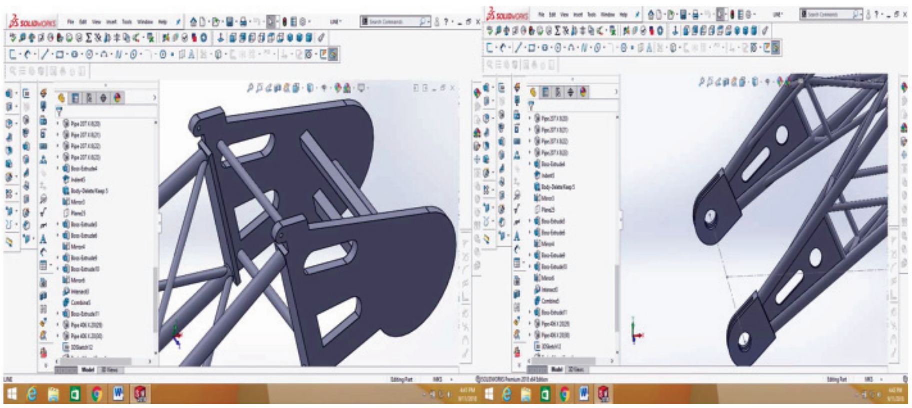

Fig.5 (a) Boom head (b) Boom foot weldment

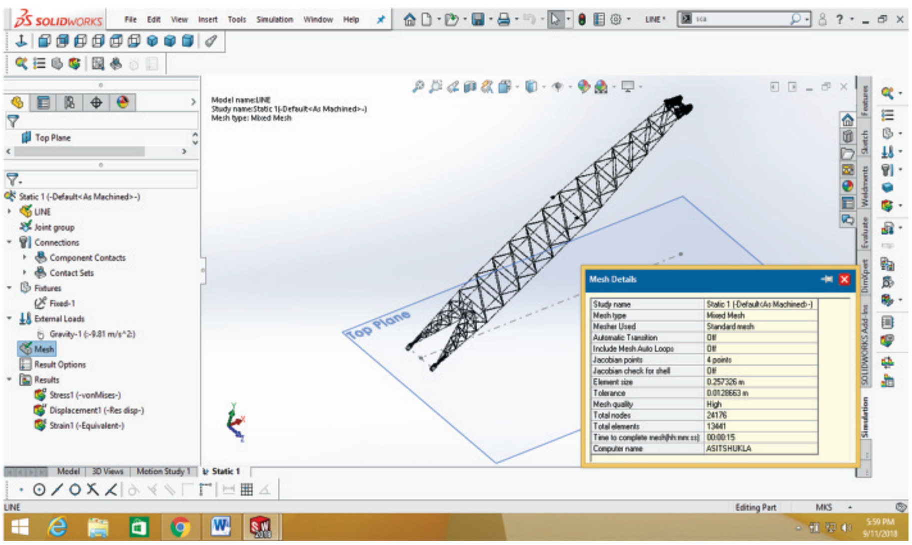

Fig.6 Meshed model in FEM environment

temperature, heat flux, and fluid velocity to name only a few. [8].

*(A) Modelling*

SolidWorks is recognised as an effective platform for designing and analysing 3D models by various industries. A 3D model is created for the dragline boom. The dimensions were recorded from a large mine. The boom length is 100 meter and inclination of the boom is 35 degrees. Figs.3 and 4 shows the actual model and cad model is created with various parts of a dragline boom respectively.

Fig.5(a)(b) shows the boom head and boom foot weldment. These are the parts which are used for fixing of boom foot with the rotating machinery and boom point sheave for hoisting applications.

*(B) Material properties*

The material selected for the analysis is alloy steel. Table 1 shows the properties associated with the material.

After assigning the material properties, the software automatically calculates the model weight and surface area. In the current model, the total weight is 234932.42 kg (approximately 235 tonnes).

*(C) Meshing*

Meshing is an important part of finite element analysis. In FEA a 3D model is divided into various small segments known as an element based on the size and complexity of the model. Due to the complexity of the model the beam elements are considered for truss members and for others solid elements are taken. Beam elements are faster to solve and provide deformation results pretty good. The mixed mesh is used, and the number of elements and nodes are found to be 13441 and 24176 respectively which are also presented by a popup in Fig.6.

Table 1: Material properties for structural steel

| Material | Alloy steel |
|---|---|
| Density | 7700 kg/m$^3$ |
| Tensile strength | 723 MPa |
| Yield strength | 620 MPa |
| Poisson's ratio | 0.28 |
| Young's modulus | 2.1 e+005 |

Table 2: Load values on the boom

| | Type of load | Value of the load (ton) |
|---|---|---|
| 1. | Self-weight of boom | 235 |
| 2. | Bucket self-weight | 70 |
| 3. | Bucket payload | 69 |
| | Total weight (1+2+3) | 374 |

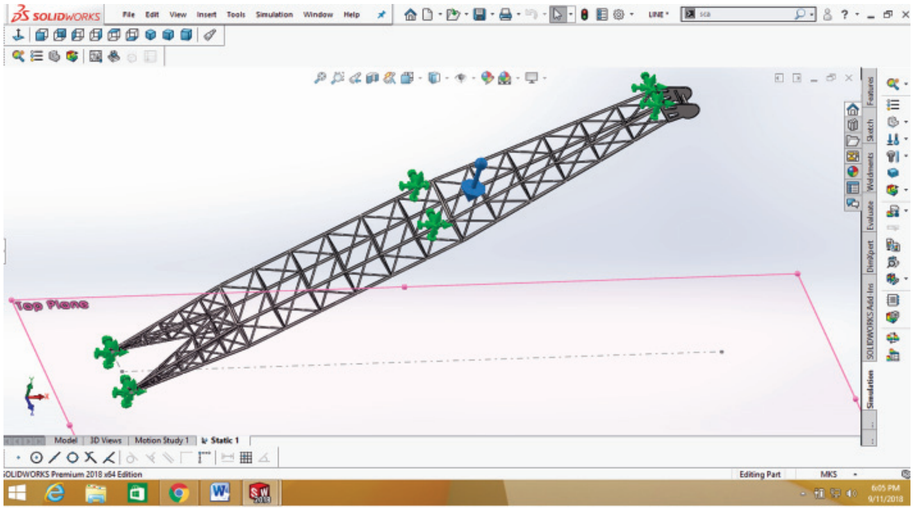

Fig.7 Boom model with fixed restraints

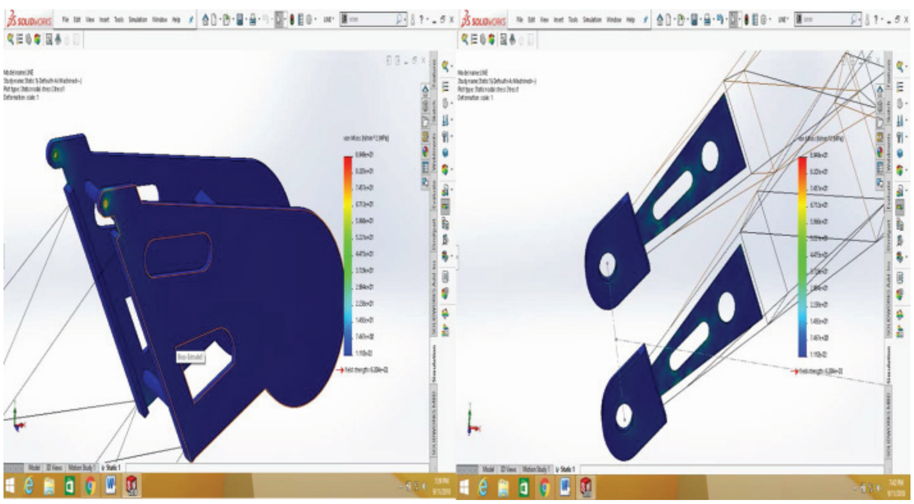
Fig.8 (a) Stresses on boom head (b) Stresses on boom foot weldment

*(E) Loading conditions*

In the present research work, three loading conditions were observed which are as follows

- A dead load of the boom (self-weight).
- Bucket self-weight is acting on boom point in a vertical direction.
- Bucket pay load is acting on the boom in the vertical direction.

Thus total load acting on the boom is the sum of the above three loads.

Table 2 indicates the values of the above three loads.

**Simulations and results**

After performing finite element analysis of the boom model, it has been observed that load acting on the boom point causes bending and axial stresses in the frame members.The main chord bears mostly compressive axial stresses while diagonal and vertical members may experience axial as well as bending stresses. The main function of the diagonal and vertical lacings is to prevent bending in the boom structure. Von –Mises stresses have been calculated in the boom head and foot weldment which are the essential parts of the boom structure.

*(D) Restraints*

These are the boundary conditions which are required for the analysis of any 3D model in cad and FEM environment. The green signs in Fig.7 indicate the fixed restraints which are the points remain fixed during the analysis. Gravity load as indicated by the blue arrow is acting on the center of mass of the body. Blue arrow shows the location of the gravity load which is acting vertically. These restraints relate our problem to the real component fixture and load application points.

(A) Boom under self-weight

In Fig.8 we can see that the stresses are concentrated near the boom point fixed. The colours show a variation of stresses on boom foot and weldment. As the boom is properly supported using suspension ropes on certain points of boom, so these points are critical from maintenance point of view. Results obtained are well within the permissible limit of material strength (620 MPa).

Fig.9 also shows the results for axial and bending stresses

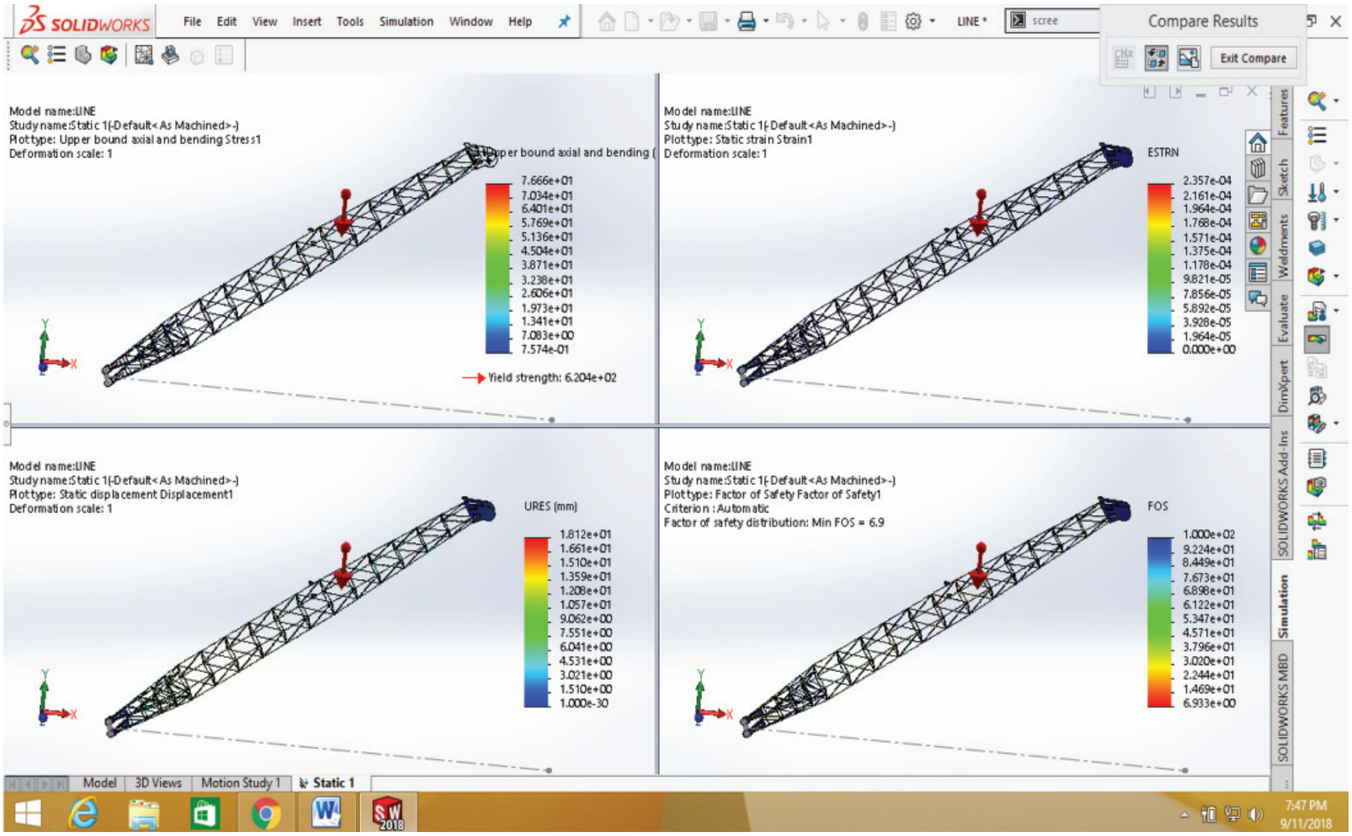


Fig.9 Results showing axial and bending stresses, strain values, deformation and factor of safety

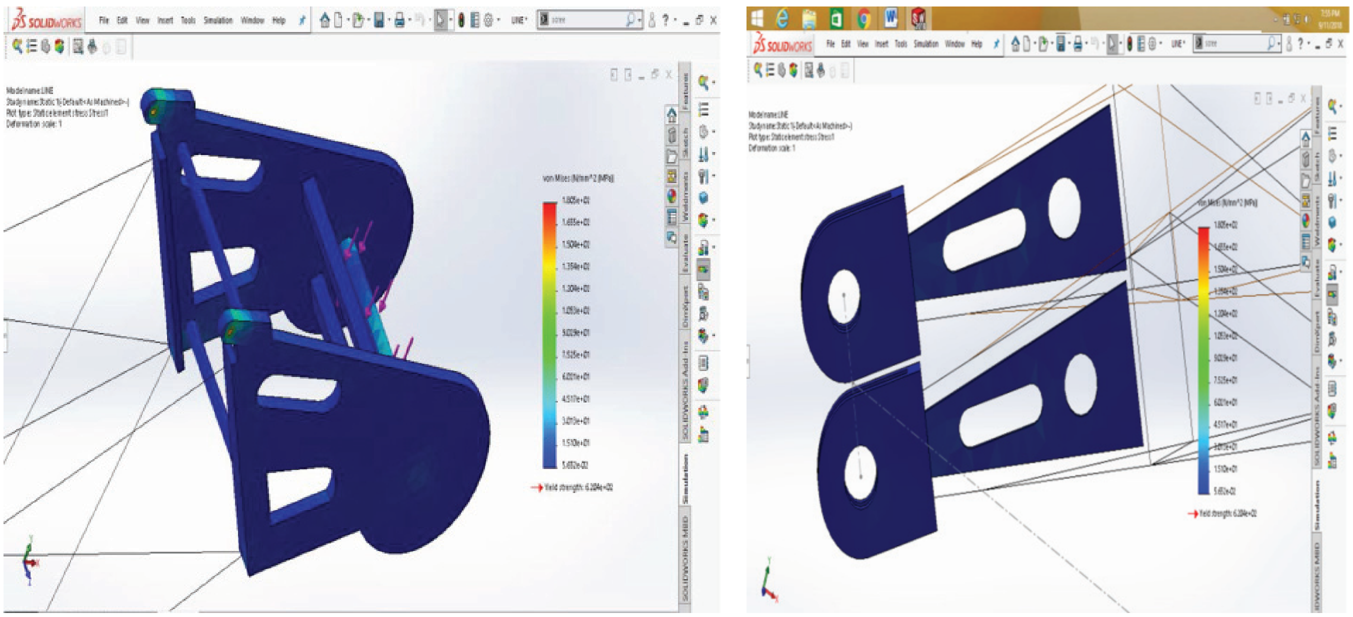

Fig.10 Stresses for maximum loading condition

are also analyzed for beam members. High value for factor of safety result shows that under the application of self-weight, the boom is safe.

(B) Boom with payload acting on boom point and self-weight

The load goes on increasing from self-weight to maximum suspended load, the load is maximum when the bucket is filled with the material excavated. In the case of this study that is 374 tonnes. By running various simulations the value of Von Mises stresses is computed to be 180MPa that is within the reasonable limit, as the maximum permissible limit of the

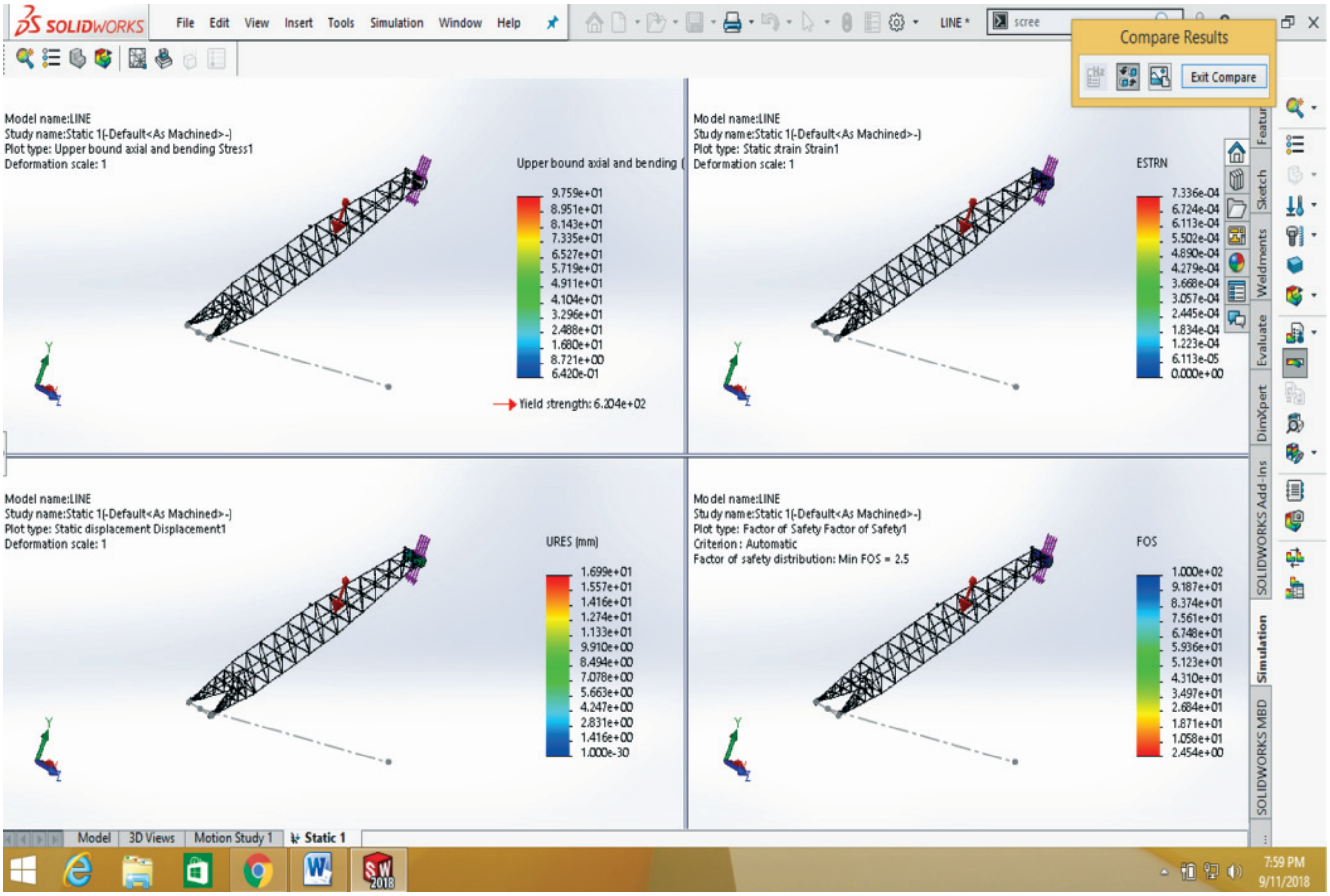


Fig.11 Results showing axial and bending stresses, strain values, deformation and factor of safety

material is 620 MPa. Now the values near the fixed point at boom head increases while that on boom foot is decreased. This is due to the fact that stresses on intermediate suspended point are increased. In Figs.10 and 11 various results are shown and their corresponding values are also depicted on vertical scale.

## Conclusions

By completing the above work, the overall behaviour of the dragline boom structure is observed. The stresses calculated are well within the yield stress of the material used. A major point of concerns is the frame structure and suspension points. Proper maintenance of these locations can prevent any major failure in these components, and optimal performance of the machine can be obtained. The factor of safety value is found to be 2.5 in case of maximum loading (bucket filled with material), which is pretty much safe. One of the major concerns of boom structure is the displacement values for frame. The boom should be supported in such a way so that during dragline operations under bucket loading, displacement should not exceed a certain value. However due to the limitation of data in the field the above results can only be used for observation purposes.

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