CHAPTER 1

INTRODUCTION

1.1 Introduction

Coal is the most important and abundant fossil fuel resource in India. The coal reserves of India are estimated to be about 326.05 billion tons and ranks fifth in the world in terms of total coal reserves (Source Annual report by Ministry of coal, Government of India 2019-20). Out of this 326.05 billion ton about 148 billion tons is the proved coal reserves of India (Source Annual report by Ministry of coal, Government of India 2019-20). The coal reserves in India are reported up to the maximum depth of almost 1200 m, with around 90% of it occurring up to 600 m depth. With the available surface mining technology, the coal is being exploited up to only 300 m currently.

Around 55 % of energy need of India is dependent on coal. Currently India is the third largest producer of coal in the world next to China and the USA; producing tremendous 729.10 MT (provisional) of coal in financial year 2019-20 (Source: Annual report 2019-20 Ministry of Coal, Government of India). Out of the 729.10 MT of coal exploited, the share from the underground mining is only 6 %. Therefore, it is obvious that open cast mining operations have tremendous significance in the Indian coal mining scenario. The open cast coal mining is largely dependent on the heavy earthmoving machineries (HEMM) for efficient production of coal. Continuous increasing demand of coal makes it necessary to explore more coal seams to meet the increasing demand. Hence, the machineries used in the mine must be capable of being continuously operated throughout the year with fewer numbers of major breakdowns. One of the most widely used machines to expose coal seams by removal of extensive overburden cover is the dragline. Draglines are giant earth moving machines used for overburden removal to uncover the extensive coal deposits. Where the coal seams are relatively available at shallow depth these machines tend to be very effective to uncover the coal seams. The rate of coal exposure depends on height of the bench, cut width, coal seam thickness, rehandling percentage on which it sits (Mohammadi M. et al., 2015). Small capacity draglines are used in construction works to dig the earth as and when required.

The draglines used in mining application can remove overburden cover up to depth of 50 m very effectively. These are heavy earth machineries with standard weight of more than 4000 tons with boom lengths ranging up to 110 m and bucket size ranging from 15m^3 to 120 m$^{3.}$ The capital cost of these machines is dependent on the bucket sizes and it is approximately Rs. 500 Crore for a dragline having bucket size of 62 m^3.

In a typical dragline excavation cycle, first the bucket is positioned just above the blasted material to be removed. Thereafter the bucket is lowered at the toe of the blasted muck pile and drag ropes are then pulled towards the bank so that the bucket can be dragged and filled with the blasted material, while dragging it against the bank (Azam & Rai, 2018). After filling of the material in the bucket, the hoist rope lifts the bucket and then the dragline boom, along with the bucket, swings to position the bucket where the material can be dumped. Thereafter, at the disposal site, the dragrope is released to tilt the bucket and dumping of the material takes place at the disposal site. Therefore, the dragline cycle consists of 5 typical segments, namely, (i) positioning and placement of bucket at the toe of the bench, (ii) dragging and filling, loading of material against the blasted muck. (iii) Swinging to the dumpsite, (iv) unloading at the dumpsite and (v) swinging back for positioning and placement at the toe. It usually takes 60 -80 sec. for a dragline cycle to be completed but it may vary depending on the material to be dig and dumping point location.

1.2 Components of Dragline

Dragline consists of various components which are as follows:

1. Mast
2. Frame
3. Boom
4. Bucket
5. Hoist rope
6. Drag rope
7. Dump rope
8. Hoist drum
9. Driving motors.

A typical dragline working mainly depends on the performance of its front end assembly, which comprises of Boom and gigantic bucket (figure 1.1). These components are also significantly important and critical from the safety point of view as they are constantly exposed to the harsh work environment. Construction wise the draglines consist of a lower and upper structure. The upper structure includes operator's cabin, various drives, and excavation and haulage units such as boom, bucket chain, metal ropes and host of assemblies (Bright, 1985). The lower structure comprises of walking mechanism and metallic chassis along with the rotating structure and tub of the dragline. The tub base of dragline bears a large amount of dragline weight (around 87% of total weight).

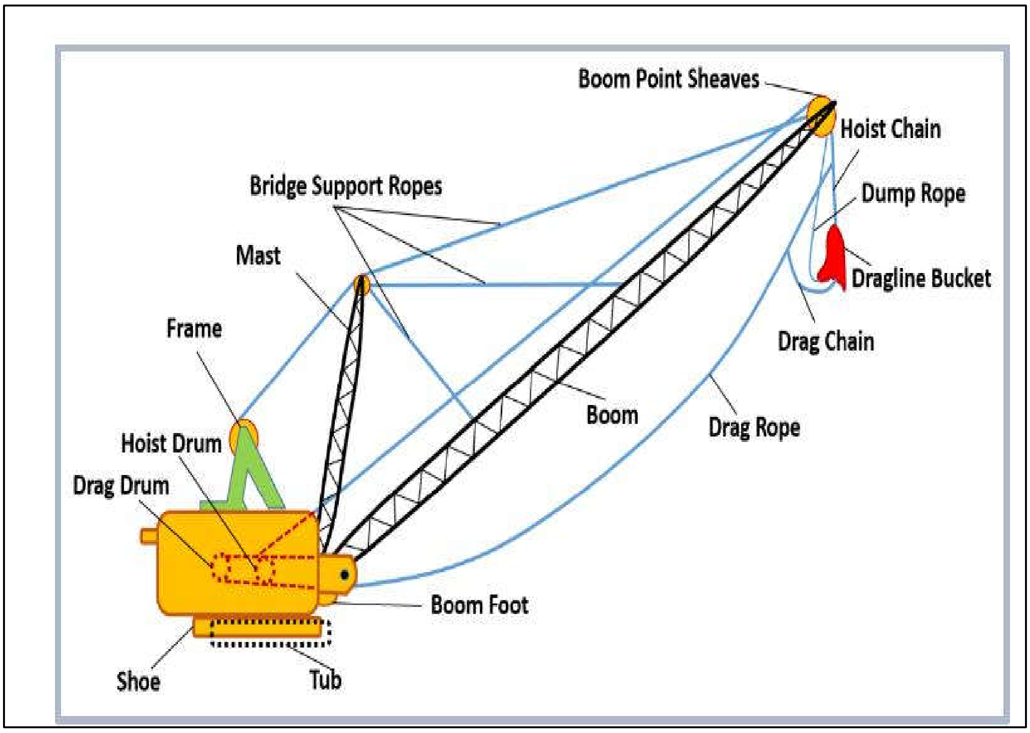

Figure 1.1 Main components of dragline (Modified from Karpuz & Demirel, 2016)

In order to ensure stability of the dragline during working, the base formation should be strong enough to bear this high load. During dragline operational cycle, as bucket is directly attached to the boom point sheave, the boom is subjected to the loading and unloading loads cyclically. This cyclic loading and unloading produces high to very high stresses in the boom structure and may lead to boom failure due to fatigue.

1.3 Dragline Boom

Dragline booms are constructed using hollow structural steel pipes. They can differ in construction depending on the manufacture and field requirements. It consists of 3 or

4 main chords and 5 or 6 bracing members connected along the length of the boom. The bracing members form complex overlapping or non-overlapping joints know as boom clusters. These clusters are the complex welded joints which may fail over a certain period of time.

1.4 Boom Configurations

The Bucyrus Erie (BE) dragline boom consists of a tubular pipe section design with a triangular cross section. The typical boom consists of three (3) main chords running the entire length with lacings connecting the chords to form a lattice type structure (figure 1.2). The chord nodes where multiple lacings intersect are identified as "clusters", the clusters are complex in the way that the lacings connect together and are a critical area for inspection. The predominant model in use in the Australian Coal Industry is the 1370 with a nominal boom length of 100m.

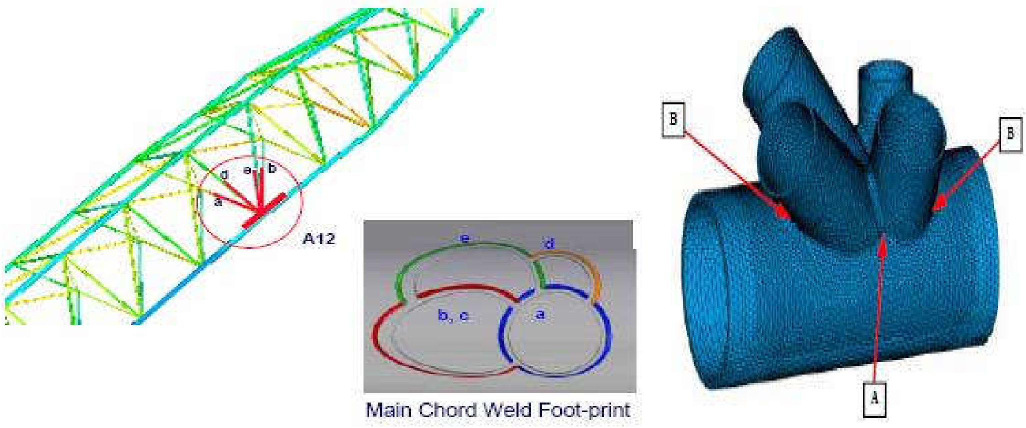

Figure 1.2 BE Boom with cluster arrangement and weld sequence Label A, B, C, A12 and a, b, c, d, e (Dragline Dictionary Edition, 2014)

The Marion and P&H booms are similar in structure utilizing a four (4) main chord design with a rectangular cross section. The main chords are I beam wide flange sections; lacings connect the chords forming the lattice in both the vertical and horizontal planes (figure 1.3). To minimize the possibility of structural failure in chords or cross lacing members, all welds and chord surfaces are visible for rapid and thorough field inspection. The nodal connections in these types of booms differ significantly in design as compared to the cluster design.

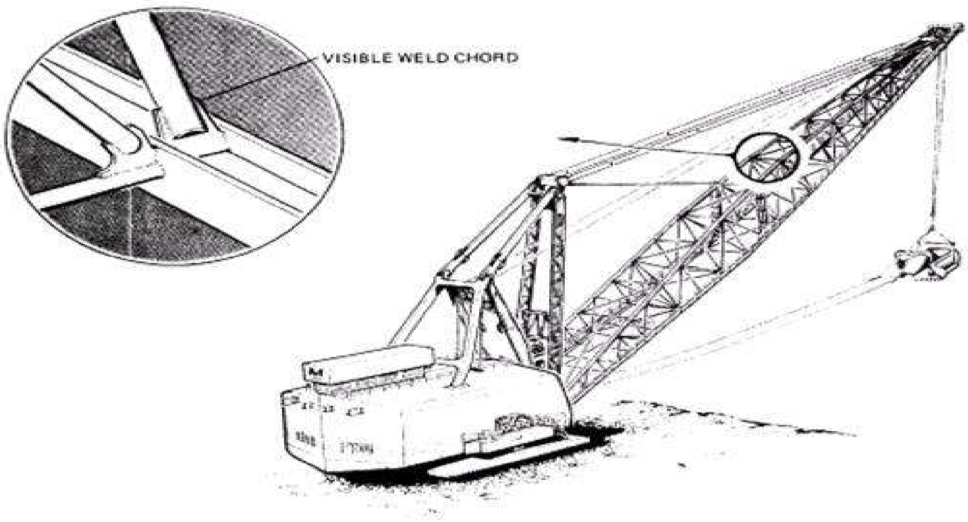

Figure 1.3 Marion Boom detailing node section (Dragline Dictionary Edition, 2014)

1.5 Dragline Boom Assembly Components

Dragline boom assembly components include mast, boom suspension ropes, boom point sheaves and boom footings (figure 1.4).

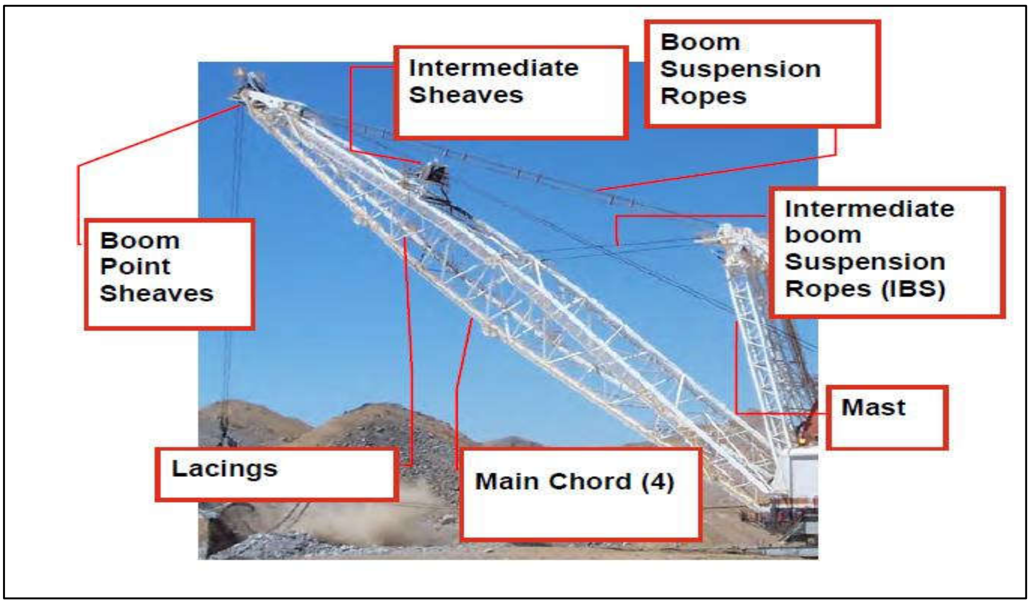

Figure 1.4 Dragline boom with its complete assembly

Boom suspension ropes are used to keep the structural deformation of boom in safe limit under the effect of self-weight and due to applied payload.

Figure 1.5 Boom foot and Boom point sheave of a dragline (Dragline Dictionary Edition, 2014)

The boom footings are an integral part of the boom structure; they connect the boom to the main chassis, (i.e. the revolving frame of the machine). These are sometimes also referred to as the Boom Root (figure 1.5). Boom point sheaves guide the hoist ropes at the end of the boom and make sure of their alignment with the direction of the ropes (figure 1.5). Operator's skill is needed to ensure a smooth operation of the dragline so that the ropes don't jump out of the sheave grooves.

1.6 Boom Suspension Ropes

These are large wound wire ropes, usually galvanized for long term protection. In normal working condition, they may last for many hours of operation (years).Most mines have non-destructive testing (NDT) programs, in place, for monitoring the ropes conditions. For effective use of multiple ropes, it becomes necessary to have regularly maintained rope spreaders to prevent the ropes wear and tear by rubbing against each other.

1.7 Intermediate Boom Suspension Ropes. (IBS)

These ropes support the boom midway to ensure flexing of the structure within the reasonable limit. Usually there are two sets of IBS Ropes for effective boom support.

1.8 Loading Conditions

In the present work, the dragline boom has been critically analyzed under static and dynamic loading conditions. Static loading condition occurs for any machine when the forces or loading do not change with time, so that we can directly apply this force for obtaining stresses in the components. On the other hand, dynamic conditions are those during which the forces or load varies with time, which implies that at different instant of time we get different values of forces on the boom. For dragline, boom under self-weight and tare weight of the empty bucket is constant load. This load is being considered as static load that does not change with time. But as soon as bucket starts digging the formation, the loading keeps on increasing filling of material in the empty bucket. This load attains maximum magnitudes soon as the bucket is completely filled. Material filling in the bucket is not an instantaneous process it occurs for a certain period of time and hence it subjects the boom to a dynamic loading condition during which, forces acting on the boom are subject to rapid increase during the filling operation. Similarly, during the unloading segment of dragline operation, the vice-versa dynamic unloading condition is experienced by the boom, wherein the boom structure gets dynamically unloaded. Given this, the dynamic conditions for the boom are experienced during the loading and unloading cycles. In the current work swing motion of the dragline has also been considered and only digging process has been simulated for the dragline operation. Proper understanding of the dragline cycle vis-à-vis the boom loading conditions must be properly understood in light of following:

1. The self –weight of dragline boom.
2. Bucket tare weight (weight of empty bucket).
3. Payload acting on the bucket.
4. Swing to motion of dragline boom with payload in bucket and,
5. Swing back motion of dragline boom with empty bucket.

1.9 Simulation Techniques

Simulation is the replica of reality. Whenever there is a need for predicting the behavior of a structure under the applied input parameters, simulation proves to be very effective. The best method for prediction of system output is to formulate a model and analyze it under real time constraints either by experiments on the physical model or by the computer based simulation techniques. In every real-time simulation, it is not possible to create the physical model of a real object or machine, so we use computer based modeling and simulation technique. The main advantage of these computer based simulation techniques is the precision, time and cost saving. The computer based numerical simulation techniques can give fairly accurate results if the models are properly constructed and boundary conditions are properly defined. The computer based numerical simulation techniques involve following steps for analyzing a real life situation.

i. Identify the problem.
ii. Formulate the problem.
iii. Collect and process real system data.
iv. Formulate and develop a model.
v. Validate the model.
vi. Document model for future use.
vii. Select appropriate experimental design.
viii. Establish experimental conditions for runs.
ix. Perform simulation runs.

Finite element method (FEM) is a numerical simulation technique. It is very effective computer based method for calculating deformation, stresses, fatigue life and various other results such as factor of safety, fatigue sensitivity etc. for a structure that cannot be tested or created physically for experiments. The structural behavior of a component under different loading conditions can be predicted and simulated using this method.

1.10 Failure criteria

Stresses in mechanical components are Von-Mises stresses. Given this, the Von-Mises stress theory is mostly used for computing the strength. The Von- Mises theory is based on maximum distortion energy contained by a material before rupture or failure. It suits very well in most cases especially for ductile material such as steel and its alloys (Hearn, 1997). The Von Mises stress computations are mainly depicted by Eq. 1.1 as given here:

$$(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma)_1{}^2 \leq 2\left(\frac{S_{yt}}{N}\right)^2 \qquad (1.1)$$

Where σ1, σ2 and σ3 are principal stress

Syt = Yield Strength

N= Factor of Safety

1.11 Statement of the Problem

In the current scenario of the country, the energy demand is very much based on the coal production. This increasing demand of coal is met mainly by the open cast methods in the country. Open cast method of mining largely depends on the equipment, which are being used for uncovering coal seams deep down the earth. Dragline finds its popularity among such machines and equipment due to absence of auxiliary haulage equipment, which, in turn, lowers the excavation cost. These machines operate continuously throughout their life time, which makes them prone to failure. Major problem of such types of machines is their failure due to fatigue over a certain period of time. It becomes extremely important to investigate stresses acting in the different components and identify the critical hot spots that are prone to failure. In the current thesis, numerical model has been created using CAD interface and structure of the boom has been analyzed in varying static and dynamic loading conditions. A simple analytical approach has been adopted to calculate the loading on the boom. ANSYS 18.0 software has been used as an effective tool for prediction of stresses in the boom structure. The fatigue life of individual joint has also been calculated and validated by the field data. Further for an individual joint, parametric analysis has also been performed by changing the joint parameters. Simulations were performed for different parametric values and subsequent values of equivalent stress (Von-Mises) have been predicted.

1.12 Objectives and scope of study

The positions of the loaded bucket with respect to the boom varies in 3D space during the operation, impact of it on static and dynamic loading on the boom at different locations are not the part of the present research work. The static load is assumed to be acting at boom point, while dynamic analysis consider swing to and swing back motion with payload only.

The basic objectives of the current work are summarized below.

1. To develop a three dimensional (3D) solid model of the dragline boom in SolidWorks software with appropriate dimensions.
2. To evaluate forces acting on the front end assembly of the dragline, this involves critical investigation of various loads and their implication on the boom, mast, A-frame and joints.
3. To simulate the developed 3D solid CAD model using finite element analysis (FEA) through under static loading conditions and dynamic loading conditions while keeping the boom angle fixed at 35°.
4. To identify the critical areas of the boom, which are prone to failure during the machine operation. Also, the values of the deformation, stress, fatigue life and factor of safety for these critical areas have been predicted.
5. To compute the axial forces in suspension ropes for assessment of loading on the dragline boom.
6. Parametric analysis of the boom by incorporating CIDECT design guidelines in order to predict stress levels in selected joint.