The present work was submitted to the Faculty of Engineering

# Transfer Chute Design Modification Using Discrete Element Method

## Bachelor Thesis

by

Sukhbat Altangerel

| | |
|---|---|
| Supervisor 1 / Examiner 1 | **Professor Ph.D. Ariunbolor Purvee** |
| Supervisor 2 / Examiner 2 | **Ph.D. Odbileg Norovrenchin** |
| Advisor | **Mr. Gurragchaa Tumur** |

Ulaanbatar/Nalaikh, August 19, 2018

# Abstract

This bachelor work is aimed to modify currently operating transfer chute design with the help of bulk material simulation. The use of Discrete Element Method (DEM) allows the engineers to design and/or optimize bulk material handling facilities with the great precision.

The latest trending simulation approach is to use DEM as it precisely calculates inter particle collision, forces that created from collision, accelerations that is created from forces, velocities and displacements for each and every particle. Bulk material flow behavior in the chute interior could be realistically predicted by DEM if it is used correctly.

The main objective of this work is to analyze existing transfer chute at Oyu Tolgoi mine, as it is experiencing high wear problem on the chute liners. Problem causing roots would be detected and analyzed for optimal solutions. Design modification would be done as one of the result of this research work.

# Acknowledgement

I would like to thank GMIT Engineering Faculty and Oyu Tolgoi LLC for giving me the great opportunity to apply my knowledge in a real life problem, and to learn from world leading organization. The completion of this undertaking would not be possible without participation and assistance of supervisors, professors and engineers from the company. Their contributions are sincerely appreciated and acknowledged.

I would like to express my deep gratitude to my supervisors Professor Ph.D. Ariunbolor and Ph.D. Odbileg for their guidance, support and patience in helping complete this thesis. Their valuable and constructive suggestions during the study and development of this research. I would also like to thank Ph.D. Taras Shepel for helping me to find literatures and sharing his ideas with me. It was a pleasure to be assisted and to learn from them. Their willingness to give their time so generously has been very much appreciated.

I wish acknowledge the help provided by company advisor superintendent Mr. Gurragchaa, manager Mr. Ankhbayar and graduate engineer Mr. Dorjsuren. These gentlemen helped to advance my ideas and were providing useful materials and information. Moreover, the company's human resources specialist Mrs. Tsolmon is wholeheartedly acknowledged due to her great assistance in organization and navigation.

Finally, I would like to thank my family and friends for all the understanding and support rendered during the course of this bachelor thesis.

# Table of Contents

# List of Figures and Tables

# Glossary of Terms

**The following abbreviations have been used:**

| | |
|---|---|
| **3D** | Three Dimensional |
| **CAD** | Computer Aided Drawing |
| **CEMA** | Conveyor Equipment Manufacturers Association |
| **DEM** | Discrete Element Method |
| **OT** | Oyu Tolgoi LLC |

| | |
|---|---|
| **Abrasion** | The process of scraping or wearing away. |
| **Adhesion** | When material sticks to surface. |
| **Angle of Repose** | The angle which the surface of a normal freely formed pile makes the horizontal. |
| **Angle of Surcharge** | The angle to the horizontal which the surface of the material forms while at rest on a moving conveyor belt. |
| **Belt** | The rubber component that carries the material on a conveyor. |
| **Bulk Density** | It is the weight per unit volume of quantity of solid particles, expressed in kilograms per cubic meter. |
| **Bulk Material** | Granular material mass transported through a conveyor system. Also called material or product. |
| **Cohesion** | When material particles stick to each other. |
| **Head Pulley** | Pulley at the discharge end of the conveyor. Belt goes from carry to return. |

| | |
|---|---|
| **Impact Zone** | Area where the particles contact the receiving belt or equipment. |
| **Lining** | Hard replaceable surface used for protection of chute structure. |
| **Material** | Used as an abbreviated form for bulk material. |
| **Product** | Granular material mass transported through a conveyor system. Also called bulk material or material. |
| **Rock Box** | The use of ledges to retain ore which in turn protects the chute structure. Side rock boxes are also denoted as side grippers. |
| **Stickiness** | Slang - Cohesion. |
| **Transfer Chute** | Structure that controls the flow of material from one piece of equipment to another. |
| **Transfer Station** | Structure that contains the transfer chute and all associated equipment. |

# Chapter 1

# Introduction

## 1.1 Overview

This chapter will outline the intent of this project and the reason why this topic was chosen as a bachelor thesis subject. Moreover, overview of the conveying system (from primary crusher to the stockpile) of the mine will be provided.

Oyu Tolgoi (OT) LLC is Mongolian government and Turquoise Hill Resources LLC co-owned company, that has high impact on Mongolian economy. OT became one of the world's largest copper-gold-silver producing mine in the last few years. OT mining operation consists of three main sectors; underground mine, open pit mine, and concentrator plan.

A task has been occurred in the concentrator plan production line that divided into 4 main areas; primary crusher (as seen in Figure 1.1), crushing and grinding, flotation and bagging plant. Ore is excavated from the open pit, then transported into the primary crusher by dump trucks, in order to reduce the product size to handle it easily. Crushed ores then transported via overland conveyor system to the stockpile. From the stockpile, products experience sequences of crushing circuit, then separation process take place. Finally, dried powder ore concentrates bagged and prepared for a shipment.

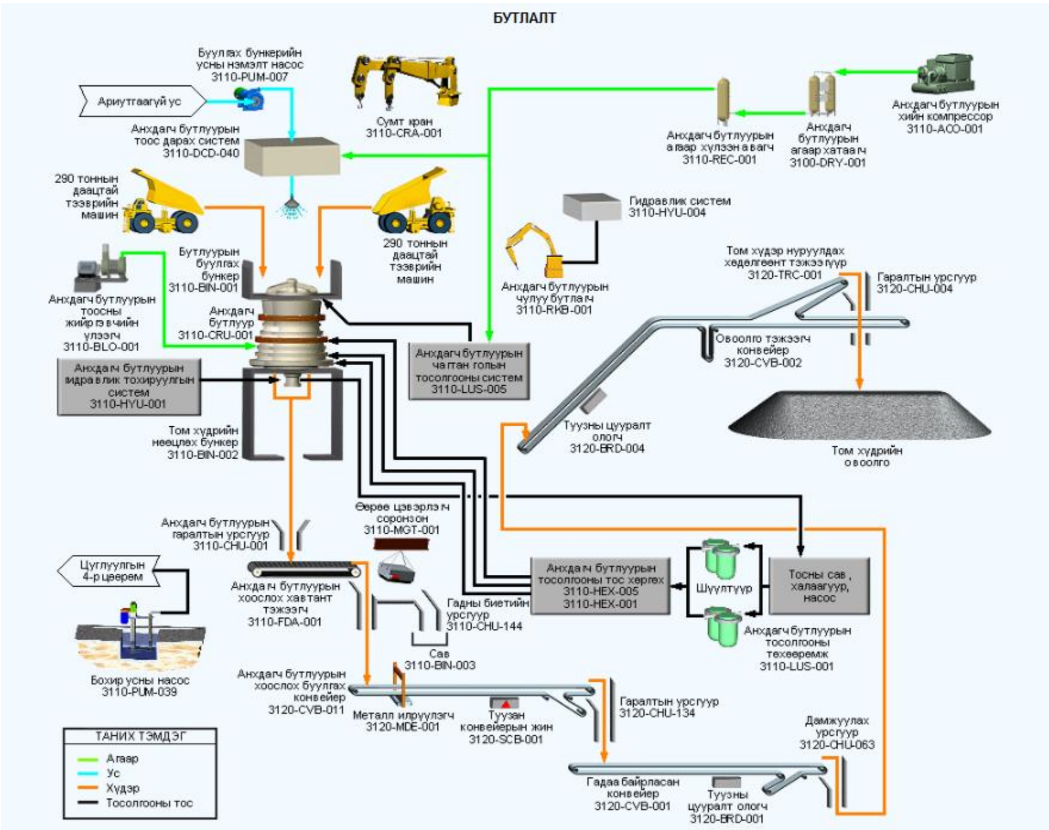



*Figure 1.1 Primary crusher flowsheet*

The conveyor system (shown in the schematic Figure 1.2) consists of 3 parts and each conjunction point has a stationary equipment to connect two parts. The first conveyor is transporting material from a primary crusher to the first transfer station, the second one is the longest one and travels from the first transfer point to the second transfer point, and the last conveyor starts from the second transfer point to dump in the stockpile.

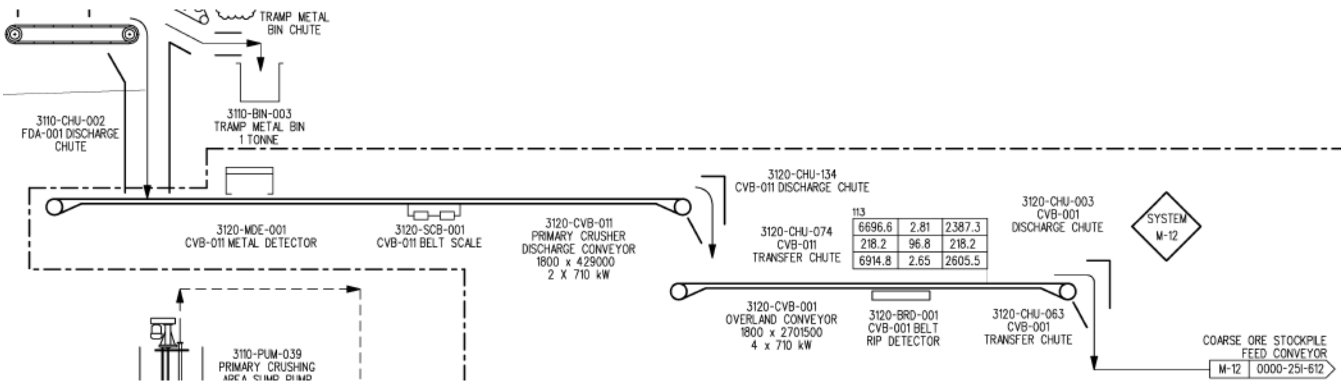



*Figure 1.2 Conveying Line from Primary Crusher to the Stockpile*

## 1.2 Problem statement and motivation

The conveying system is currently experiencing high wearing problem with the transfer points. This transfer stations mainly make the whole conveying system and the primary crusher to stop in order to do planned maintenance or due to unplanned maintenance. These downtimes do not only seriously affect the maintenance team performance but the more money and time could be saved. At present planned maintenance stop takes place in every four weeks and the maintenance team aims to extend it to the eight weeks.

This research is purposed to find a solution to solve a high wear problem in the transfer chute CVB001 (refer to Figure 1.2). High friction between the bulk material and the inner surface of the chute causes high abrasive wear on the chute liner plates. Hot zones are inclined side walls and back edges that is shown in the Figure 1.3, Figure 1.4 and Figure 1.5.

*Figure 1.3 Inclined side wall*

*Figure 1.4 Back edge*


*Figure 1.5 Side wall before and after changing liner plate*

Maintenance team tries to overcome a problem by attaching grips (see Figure 1.6) to the side walls to increase ore to ore impact instead of ore to chute impact.

*Figure 1.6 Grips attached to the chute wall*

These attached grips significantly reduce the direct contact between the material and the inner surface. However, these grips raise another problem which is making the maintenance more difficult. During the cold climates, materials that are collected in the grips are hard to remove, hence technicians hit it with breakers. Thus, current design is not sufficient enough, and safe working environment is missing at the moment. Therefore, this bachelor work is intended to overcome an above mentioned problem and motivated to extend planned maintenance interval into eight weeks.

## 1.3 Contribution

In this thesis the concept of Discrete Element Method (DEM) is used to simulate ore flow trajectory and interaction behavior between ore and chute surface.

The issue is only considered from the design side without reflecting any material enhancement (e.g. changing liner material composition) and/or overall system modification (e.g. using different type of chute).

To get successful solution following tasks have to be made:

- Reviewing conventional design methodology
- Reviewing state of the art design methodology
- Defining bulk material properties and interactions
- Define and model current chute design
- Optimize chute design to reduce wear

## 1.4 Outline

The research will present the optimization of chute design with the help of Discrete Element Method, in order to reduce abrasive wear on the side walls. The study is organized as follows.

Chapter 1 outlines the intent of this project and the main goal that has to be achieved. Additionally, this chapter provides brief overview of the OT conveying system.

Chapter 2 provides a theoretical background of DEM concepts and the bulk material handling facility with main focus on transfer point. Chute design methods, common issues related to inadequate design, and the bulk material behavior will be described.

Chapter 3 will review on-going chute design and its cad model. Furthermore, chute designing analytical methods and design considerations would be presented.

Chapter 4 will present DEM simulation made in current and optimized chute design. Moreover, the simulation results would be described and analyzed for possible solutions.

Chapter 5 and Chapter 6 conclude the research work and introduce important future study concerns.

# Chapter 2

# Background Research

This chapter will provide a brief knowledge about bulk material handling facilities with a specific focus on transfer chute design methods, design decisions and common issues that could cause in inadequate chute design. The chapter continues with the fundamental knowledge of DEM software and its use in bulk material handling industry. The use of this work will be used to obtain optimal chute design.

## 2.1 Introduction

Conveyor belts are widely used in various industries to deliver bulk materials from one point to another. Conveyor transfer stations are a crucial part within the conveyor track in many industries that handle bulk materials. The material has to be guided from discharging conveyor to the following transport system. Conveyor belts move solely straight, hence conveyor belts have to be redirected and/or it has to overcome any vertical transfer height. This transfer point is realized by using transfer chutes, which have to be designed in such a way that dust, noise and wear are minimized. The chute is defined in the oxford dictionary as "*A sloping channel or slide for conveying things to a lower level*".

Following studies (1,2) stated five basic design objective for chute:

- To guide material on to a conveyor belt, at the speed of the conveyor belt, in the direction of belt travel
- To eliminate material spillage
- To enclose material dribbles
- To enclose material from operating personnel
- To eliminate dust liberation
- To minimize material degradation
- To maximize the surcharge angle on the receiving conveyor
- To effectively clean the belt, to minimize carry-back

- To effectively control the transfer of the material

Andrew P. Grima et al. (3) mentioned in his research report:

“It would be ideal to have no transfer point in production line; however, with the limitations of idler conveying technology and plant design, more often than not, transfer points are required”.

Without considering any other aims but only transferring from one to another belt, simple transfer chute designs are relatively easy, especially if it is handling dry and uniform products. However, it is more complex in a real life and transfer chutes tend to require more service also could cause more downtime than conveyors or the following equipment.

Transfer chutes have a critical economic importance in a production line. With the correct chute design the ore can be controlled such that it is presented to the conveyor with the same velocity, thus reducing belt wear. Alex Mason (4) expected replacement cost of conveyor belts can run into the 100.000 USD, not including the associated project and downtime costs that are inherent in a belt change out operation, accurate prediction in the material behavior at the discharge end becomes highly significant.

Colin Benjamin (5) states in his book *The Transfer Chute Design Manual* that the reason behind the simplified and poor chute design developments are mainly economical. As summarized by him:

‘Time and money drives our industry so it is not surprising that as banal as a transfer point in a conveyor system can be overlooked or poorly considered during any initial designing of a materials handling facility’.

Therefore, engineers design transfer chutes based on general rule of thumb and their own experience. These transfer chutes are basically designed based on previously built transfer chute designs or conventional guidelines from recent projects with similarity. Some material properties such as angle of repose and friction coefficients are determined by field tests in newly developing projects. By evaluating this material properties one can choose historical chute designs that is best suited to the current situations.

An existing chute modification generally based on trial-and-error basis and mainly focused to increase performance and reduce downtime. This bachelor thesis is scaling and modelling also collecting information from the existing model to develop its design.

Moreover, a significant cost benefit could be achieved if the improved chute design reduces downtime required to repair damaged parts.

## 2.2 Literature Review

A literature review has been done to collect a knowledge, and to further develop the idea towards a research aims. The purpose of the review was to gather relevant information about:

- Review of current design methodology
- Typical problems and issues from poor and/or inadequate design
- Material properties
- What is Discrete Element Modelling
- Limitations of Discrete Element Modelling

### 2.2.1 Review of Current Design Methodology

Basic transfer chute designing process begins with examining the material that is being handled, throughput requirements and the feeding and the receiving equipment. Minimum slope angles allowable for material to freely slide along the surface (6) are determined, and then from this angle a minimum height between discharging and receiving conveyor could be calculated. From this point, additional equipment such as belt scrappers, access doors and so on could be considered.

A more advanced design consideration could include material flow trajectory calculation based on projectile motion equation. Rough estimation of material path in the transfer chute can be made by these calculations. It allows a designer to predict initial and high impact points, which gives advantage to the designer to implement rock boxes, high impact liners and deflectors.

Several methods are available to calculate trajectory path. Colin Benjamin (5) reviewed the most proven methods from following authors and associations:

- Method of Korzen
- Method of Booth
- Method of Golka
- Method of Dunlop
- Method of Goodyear
- Method of MHEA (Material Handling Engineers Association)
- Method of CEMA (Conveyor Equipment Manufacturers Association)

None of this mathematical models cannot exactly represent the real life trajectory, especially flow behavior after the impact in the chute. Benjamin stated the best method in determining trajectory is investigating and scale modelling.

Previous research (5) stated the simplest method of controlling the material flow through the transfer chute is to allow material to gravitationally slide along the inner surface of the chute. With the help purposely placed inclined walls can control the direction and the velocity of the material flow. Based on practical experiences in the field the minimum internal wall angles set at 70° to horizontal which is substantially greater than angle of repose plus 5°. The shallowest angle is the internal valley angle between two surfaces that is shown in the Figure 2.1 from Andrew L. Mular (7).

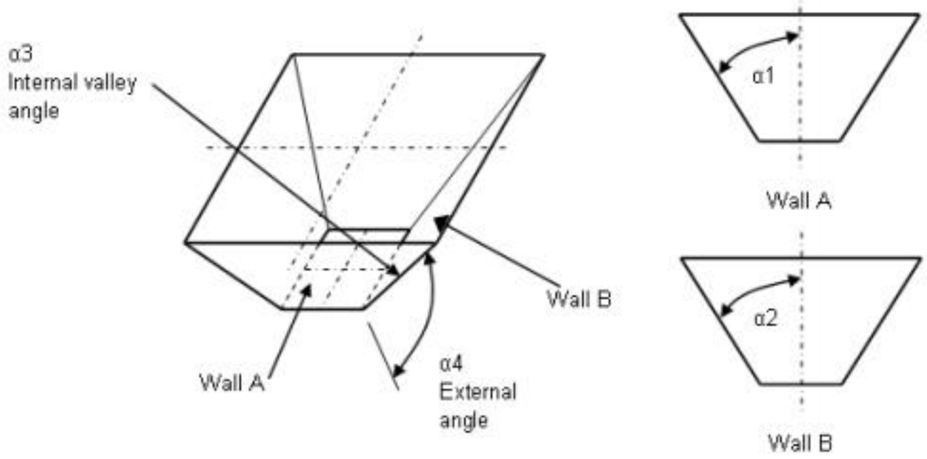



*Figure 2.1 Valley angle*

Main disadvantage of this method is increased wear on the side walls. Reducing the chute angles too much would cause possible damages, including blockage or overloading. Benjamin et al. (5) stated chute internal angle must be greater than materials angle of repose and notes that other factors such as particle to particle, particle to wall friction, rolling friction expected bed depth and the materials cohesiveness must be considered. This is similar to Arnold (8) where he states that the chute angle should be 5° greater than the maximum friction angle between wall and the material to prevent capacity restrictions.

Another method to control material flow is by using impact plates (also known as deflectors) such as the one shown in the Figure 2.2 (9). It is a very basic method of controlling the direction of the flow through the chute and these plates usually made out of hardened steels with high wearing protections. Impact plates could set as an adjustable by using impact sensors or manual tuning which makes this method advantageous.

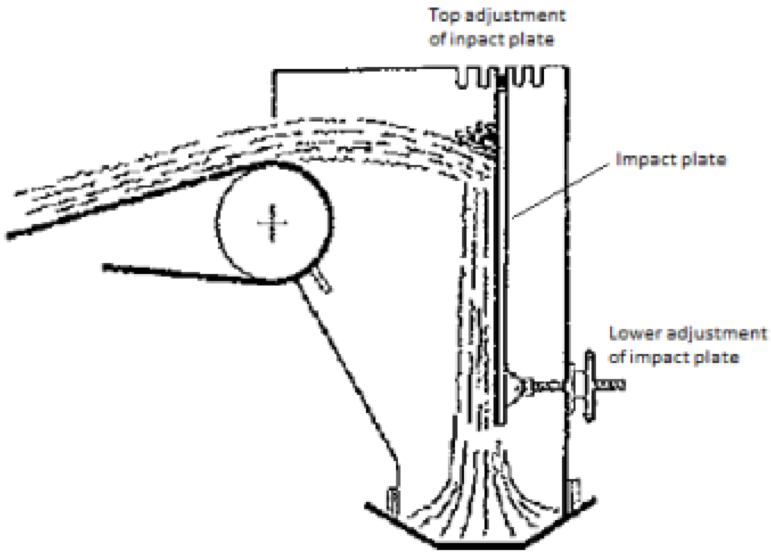



*Figure 2.2 Impact Plate*

The rock box was developed to absorb the high energy impact associated with handling large rocks that would otherwise severely damage or cause the receiving belt to be ripped. It is designed as a rock ledge in the form of an open box such that material can flow into the box and as it fills, overflow onto the receiving belt. Some original designs allow the box to be empty however the most designs today rely on the box always being filled with the material and the material itself as the impact or wear surface (also known as autogenous rock box). In order to retain material in the box there can be small ledge at the front opening of the box. When the set up correctly the ore will assume an angle of repose dependent on the ore type of usually between 35 – 45 degrees and it is from this surface the ore deflects onto the receiving belt. If the height of the chute is significant, then sequential rock boxes can be employed to create a cascading effect down the chute.

They do however have a number of issues which have to be considered carefully before applying rock boxes in the chute design:

- As they slow the material flow through the transfer significantly, they become limiting factor in the capacity of the conveyor system.
- They do lead to material degradation, dust and noise emission.
- When handling wet and cohesive material they are prone to blocking from excessive build up therefore they require regular cleaning out.
- The product lands on the receiving belt with little or no horizontal velocity. As the belt has to fully accelerate the material, there is increased belt wear and power consumption.

In the Figure 2.3 (9) typical rock box design is illustrated.

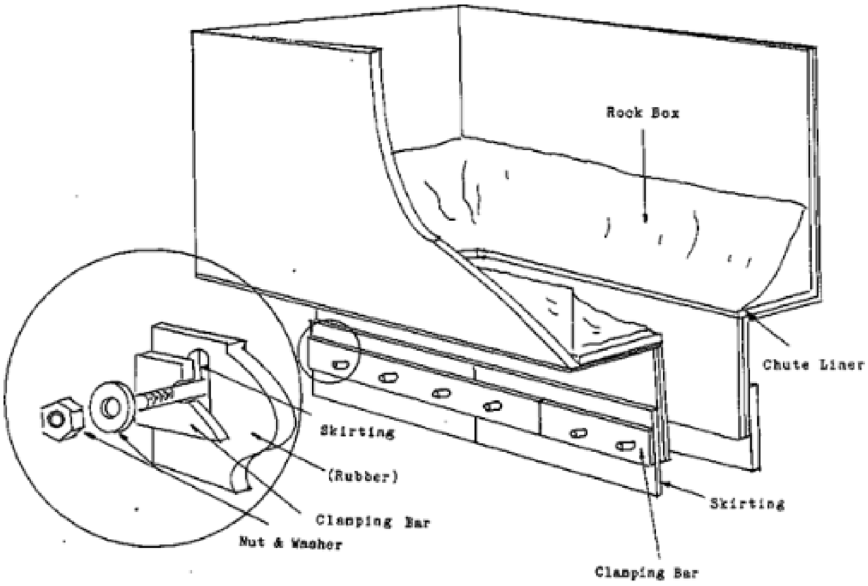



*Figure 2.3 Rock Box*

## 2.2.2 Common issues with chutes

The methods previously mentioned in subchapter 2.2.1 try to solve variety of issues found in transfer chute. Unfortunately, solution to one issue often cause another issue. In this section investigation on some of these problems will be described and available design techniques to resolve them will be considered.

The following list taken from Adi Fritella el at. research (10) introduces the possible difficulties that could occur during transferring operation:

- Spillage
- Load zone turbulence
- Load centering
- Poor skirt board seal
- Impact idler maintenance
- Inadequate skirt board length
- Dust control
- Material degradation
- Belt tracking
- Poor provision for clean up
- Inadequate provision for belt cleaning equipment
- Inadequate skirt board length
- Chute wear

- Belt damage from large lumps
- Belt wear and abuse
- Material build up –plugging
- Noise
- Structural support of chute and skirt
- Lack of attention to the detail design
- Loading onto transition area
- Corrosion
- Unknown material characteristic
- Economic considerations
- Safety issues
- Housekeeping

The most of the bulk materials are abrasive which makes the structural wear develop at the contact point between chute inner surface and bulk material. This wear is proportional to the impact energy between the material and internal surface of the chute. The most common method to reduce the wear is to apply more abrasive wear resistant material. Slowing the ore flow through the use of chute geometry is another method in reducing chute wear, allowing the ore to ore impact more and reducing ore to the inner surface impact. However, it has to be considered carefully due to risk of flow restriction through the chute. Using rock boxes at the impact point is robust and cheaper than using wear resistant liner for dry materials.

Flow restrictions mainly arise due to inadequate incline of the chute inner surface and dead zones. This type of issues prevalent in cohesive materials. Material slows down and builds up through fiction along the chute sliding surface it allows material to build up more and more till it reaches the opposite and to block whole flowing path. Figure 2.4 (11) shows the DEM model of coal transfer chute. The figure in the left side shows flow restriction, as material is slowing and building on the inclined surfaces. The right side figure shows improved chute design with increased chute inner surface slope that allows material flow frequently.

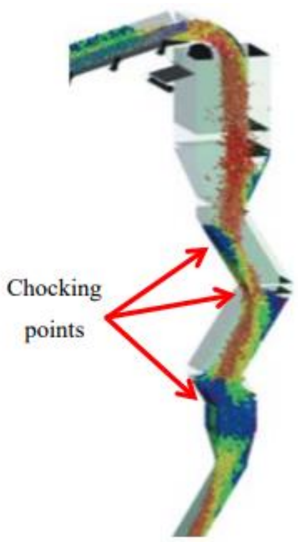



Figure 2.4a Poor design

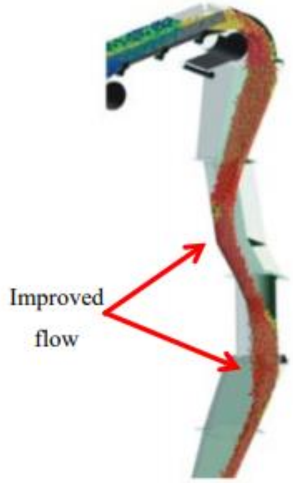



Figure 2.4b Improved design

One of the fundamental requirements for chute design to load the material centrally on the belt as a result of research from Benjamin et al. (5). Otherwise, material will be loaded on the side idlers and as material centralize itself due to gravity belt will be dragged to the side. This problem would cause malfunction of conveyor belt, spillage also increases hazard risks.

Poor flow control at the chute discharge causes significant abrasive wear on the receiving belt. When material hits the belt, wear is proportional to the impact pressure and diffrence between horizontal velovity of material and belt speed.

One of the most environmentally hazardous side effect of ransfer chute is a generation of dust particles. Generally dust is considered a biological hazard due to issues associated with inhalation and skin/eye irriataion (4). In addition to environmental effect, conisderation is given to product loss and material degradation of associated equipment. Dust issue is mainly related to handling dry and fine particles. Another possible threat is risk of explosion due to high intersurface interaction.

Plenty of methods are available at the martket for controling dust that isolates the chute station and use extraction fans to create negative pressure inside. These methods are expensive and require additional infrastructure that separates dust from an air. Water and/or foam spraying method is widely used in the industry but this technique has to be considered very carefully. Material mass could increase significantly due to inappropiate usage of spraying method, which would lead to higher power consumption and most importantly stickiness of the material could increase, that leads to material build up in the chute cavity.

The simplest method that mentioned in the recent research work (4) is regulating ore flow to prevent separation of particles as it falls through the chute. As the material discharges from the upper conveyor, gradients of particles velocities develop based on the distance from pulley centerline. The variation of particle speeds creates separation in the ore flow and this separation draws and traps air in the material flow until it impacts on the belt. On the impact the air is expelled from the material carrying the smaller and lighter particles with it in the form of dust. By controlling the flow so that the stream remains as compact as possible, with minimal separation of the particles, dust generation can be significantly reduced.

### 2.2.3 Bulk solids properties

C.R. Woodcocks et al. (12) state a definition for bulk solids is ‘It consists essentially of many particles or granules of different sizes (and possibly different chemical compositions and densities) randomly grouped together to form of a bulk.’ The nature of such a material depends upon many factors, but principally upon the size, shape and density of the constituent particles. These properties are closely related and should be considered together. These interactions, in turn, influence critically the behavior of the bulk material e.g. its flow ability, fluidizability, compressibility, toxicity, flammability and explosibility. Unfortunately, the relationships between these basic parameters and the practical behavior of bulk materials are not yet fully discovered. At the present time level of knowledge in this field is not sufficient enough to predict bulk solid behavior only based on its constituent particles.

Recent research (12) indicates there are two different levels of bulk solid characterizations:

- ‘By means of features descriptive of the behavior of the material in its normal bulk form; for example, the way in which it compacts, its flow properties, the influence of moisture and electrostatic charging
- By means of features of the constituent particles such as their size, density, hardness, shape and surface texture.’

Bulk materials are characterized by:

- Granulation or dustiness,
- Density,
- Natural angle of repose,
- Internal friction
- Static and kinetic friction
- Hardness
- Attrition
- Crushing sensitivity
- Change of properties due to vibrations, temperature, water or humidity
- Adhesion

- Plasticity
- Electrostatic properties

These are main factors according to literature (13), both particle and bulk forms are related to these properties. In this section four main properties and their identifying method will be described;

- Bulk density
- Material size and shape
- Angle of Repose
- Surcharge angle

The bulk density of a particulate material is defined as the weight per unit volume of a large group of particles. A geometry of constituent particle is depending upon their method of production, irrespective of whether they are of regular or irregular shape, when they are packed together in random orientation there will be certain amount of free space between them. Thus a bulk solid is certainly a combination of constituent particles and free space, the percentage of the total volume that is not occupied by the particles usually being referred as the 'voidage', 'void fraction' or 'porosity'. Previous study (12) defines typical values of the voidage in static bulk materials consisting of mono sized spheres would range from 0.26 for hexagonal packing, to 0.48 for regular cubic packing. Simple sources (14,15) noted the equations of bulk density and voidage as shown in 2.1 and 2.2.

Thus

$$\text{voidage, } \varepsilon = \frac{volume\ of\ voids}{total\ volume}$$

or

$$\varepsilon = \frac{V_{voids}}{V_{particles}+V_{voids}} \tag{2.1}$$

and, in a bed of material having unit volume, the actual volume of solid particles, or 'fractional solid content', is (1-ε). The bulk density can be defined as the ratio between mass of the material and its total volume.

$$\text{bulk density, } \rho_b = \frac{m_{solid}+m_{void}}{V_{solid}+V_{voids}} \tag{2.2}$$

It is important that the distinction between the bulk density of a particulate solid and the true density is clearly understood. For a single particle the density is defined as the mass of the particle divided by its volume, so that for a bulk material average particle density can be determined by dividing the mass of material by the true volume occupied by the particle (not including void volume).

To get more detailed information about standards, tables and measuring methods one can see the literature (16: p.8-11)

Particle size, shape and surface area are fundamental characteristics of bulk material and are paramount importance in most unit operations. They determine very large extent degree of interaction between particles and their surroundings. In general, no universally accepted method has yet emerged to define and classify particles according to their geometry. Several studies (12,17) have considered classification of the bulk solid according to their particle size. Ore products which have experienced primary crushing stage obviously considered as a coarse (or broken) solid, typically size range in between 5 to 100 mm. For spherical particles, the size is defined only by its diameter. However, with the exception of few powders, the most of the industrial materials are irregular and the definition of particle size presents some difficulties. Therefore, shape of particle is equally important and needs to be specified also. Particles shapes may be defined in several ways. One approach (18) is to define sphericity of the particle:

$$\text{sphericity, } \psi = \frac{surface\ area\ of\ sphere\ having\ the\ same\ volume\ as\ the\ particle}{surface\ area\ of\ the\ particle}$$

or,

$$\psi = \left[\frac{d_v}{d_s}\right]^2 \qquad (2.3)$$

where dv is the diameter of the sphere that has same volume as the particle and ds is the diameter of the sphere with the same surface as the particle. For spherical particles, sphericity equals to 1. P.A. Shamlou (17: p.4-6) states a relation between sphericity and the flowing behavior as particles become less spherical, consequently less flow able and more difficult to handle as it deviates from unity. Furthermore, the study contains further methods, equations and tables for shape defining methods.

The angle of repose is defined in Oxford dictionary as "*The steepest angle at which a sloping surface formed of loose material is stable."* It could be measured simply just pouring the particles from above till it forms stable pile that is shown in Figure 2.5 (19).

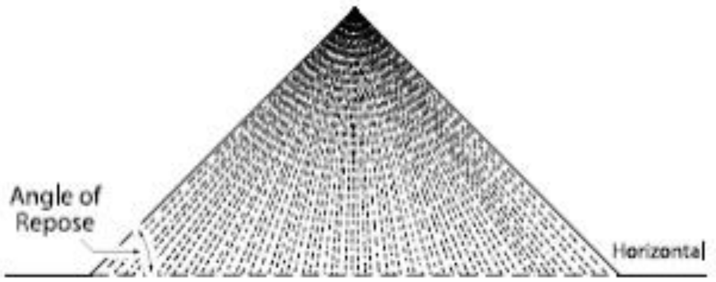



*Figure 2.5 Angle of Repose*

Piotr Kulinowski (13) describes the angle of surcharge of a material as the angle to the horizontal which the surface of the material assumes while the material is at rest on a moving conveyor belt. The surcharge angle is measured after settling through vibration has applied and used in determining cross sectional shape the material forms on a conveyor screen as seen in Figure 2.6 (20).

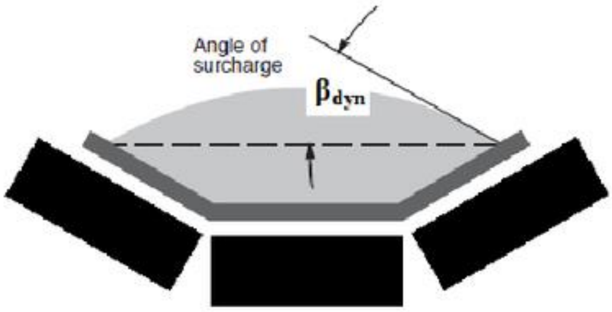
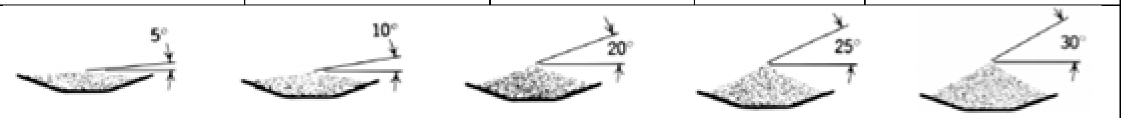



*Figure 2.6 Surcharge Angle*

The relation between flow ability – angle of surcharge – angle of repose is shown in the Table 2.1 that has been exclusively sourced from (13).

| **Flow** | | | | |
|---|---|---|---|---|
| Very free flowing | Free flowing | Average flowing | | Sluggish |
| **Angle of surcharge** | | | | |
| 5° | 10° | 20° | 25° | 30° |
|  | | | | |
| **Angle of repose** | | | | |
| 0 - 19° | 20 - 25° | 30 - 34° | 35 - 39° | 40° - up |
| **Material characteristics** | | | | |
| Uniform size, very small, rounded | Rounded, dry polished particles, | Irregular, granular or lumpy | Typical common materials | Irregular, stringy, fibrous, interlocking |

| | | | | |
|---|---|---|---|---|
| particles, either very wet or very dry, such as dry silica sand, cement, wet concrete, etc. | medium weight, such as whole grain and beans. | materials of medium weight, such as anthracite coal, cottonseed meal, clay, etc. | such as bituminous coal, stone, most ores, etc. | material, such as woodchips, bagasse, tempered foundry sand, etc. |

*Table 2.1 Flow ability – Angle of surcharge – Angle of repose*

The literature (4) remarks some of the most important property measuring methods as 'Materials internal friction coefficient is directly dependent on internal shear stress limit, which can be measured indirectly by determining the maximum force per unit area at which the material can resist separation from externally induced compression or sliding forces.' A typical shear sell show in Figure 2.7 (19) shows how the shear stress – S and consolidated force – V are determined. The shear and consolidated forces are used to determine flow ability of the material.

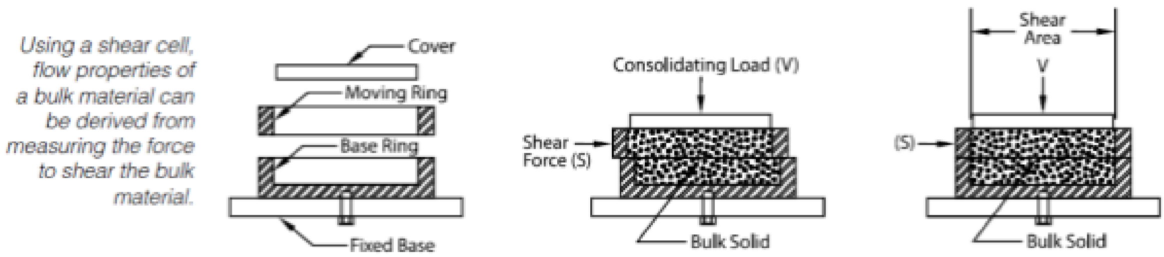



*Figure 2.7 Shear Cell*

Swinderman et al. (19) provides Figure 2.8 a Mohr's circle is created and by increasing the consolidating force and associated shear is measured in order to determine internal friction coefficient, as seen in Figure 2.9.

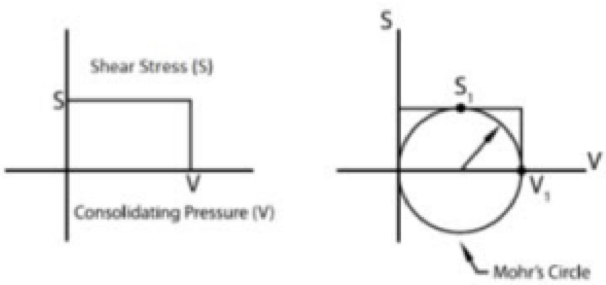



*Figure 2.8 Mohr's Circle*

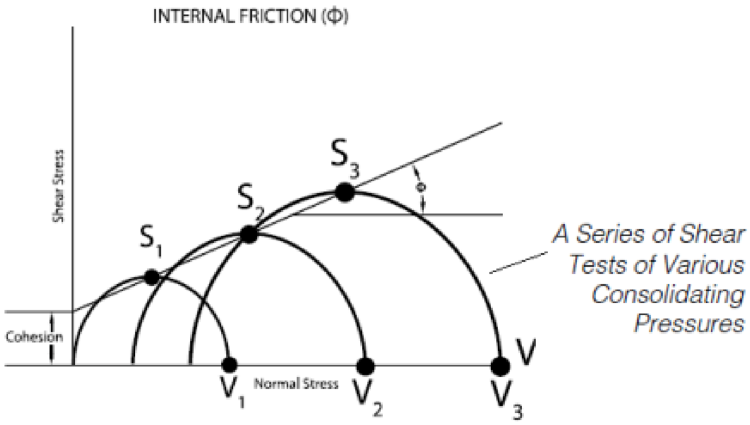



*Figure 2.9 Internal friction angle*

Wall friction is determined in a similar testing method, with the main difference being it is measuring the materials resistance to sliding over a surface rather than through the internal shear as can be seen in the Figure 2.10 (19). The coefficient of friction - μ is equal to the tangent of the wall friction angle - θ, and there is an inverse relationship between the consolidated pressure – V and wall friction angle.

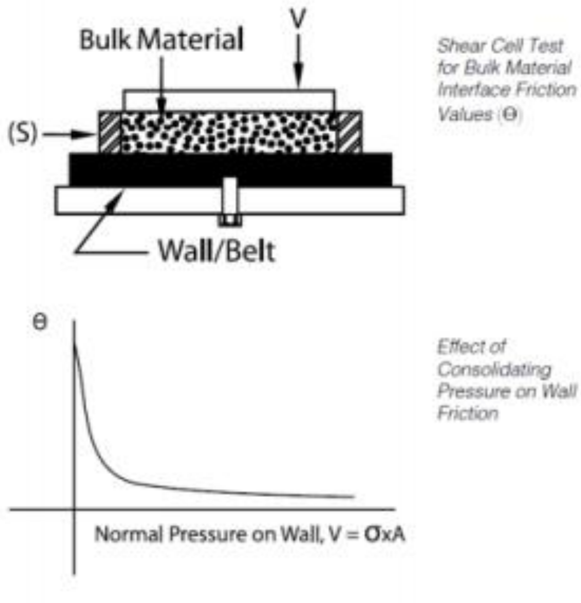



*Figure 2.10 Wall friction*

The literature (4) defines 'Adhesion - σ is the materials ability to resist movement at zero normal stress. Cohesion – τ is the materials ability to resist shear at zero normal stress' as seen in Figure 2.9. Adhesion and cohesion could be found from the shear cell test. Cohesion and Adhesion are related to the wall friction, shear stress and consolidated pressure by formula below:

$$tan\theta = \frac{S}{V} = \frac{\tau}{\sigma} = \mu \qquad (2.4)$$

Moisture content is the amount of water in the material which is related to the cohesiveness and adhesiveness of the material. The moisture is a percentage of total wet weight of the material. It could be defined by measuring the weight before and after the drying process. It is divided into two types:

- Surface water – Water that is free on surface, between particles and open pores
- Inherent water – Water that is contained in the closed pores.

## 2.2.4 What is Discrete Element Method

Two main modeling approaches are available to simulate particles in the industry, which are continuum (Eulerian) and discrete (Lagrangian).

In the continuum approach, constitutive behavior of bulk material is described by constitutive laws, generally expressed in the form of differential equations which relate mechanical field variables (e.g. stress and strain). This modelling approach assumes that it continuous and completely fills the space it occupies. As a result, individual particle behavior is neglected. The resulting constitutive equations solved numerically (e.g. Finite Element Method).

In contrast to continuum approach, discrete methods model each single particle as a distinct entity and represent granular particles as an idealized assembly of particles. The overall system behavior results from individual particle interactions. This makes the discrete approach very good for investigating phenomena occurring at the length scale of particle diameter and simulating bulk behavior of particles.

Visual representation of both methods are shown in the Figure 11.

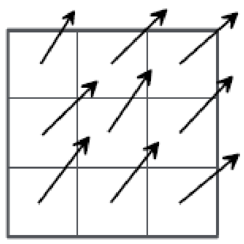


*Figure 2.11a Continuum approach*

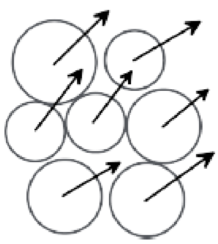


*Figure 2.11b Discrete approach*

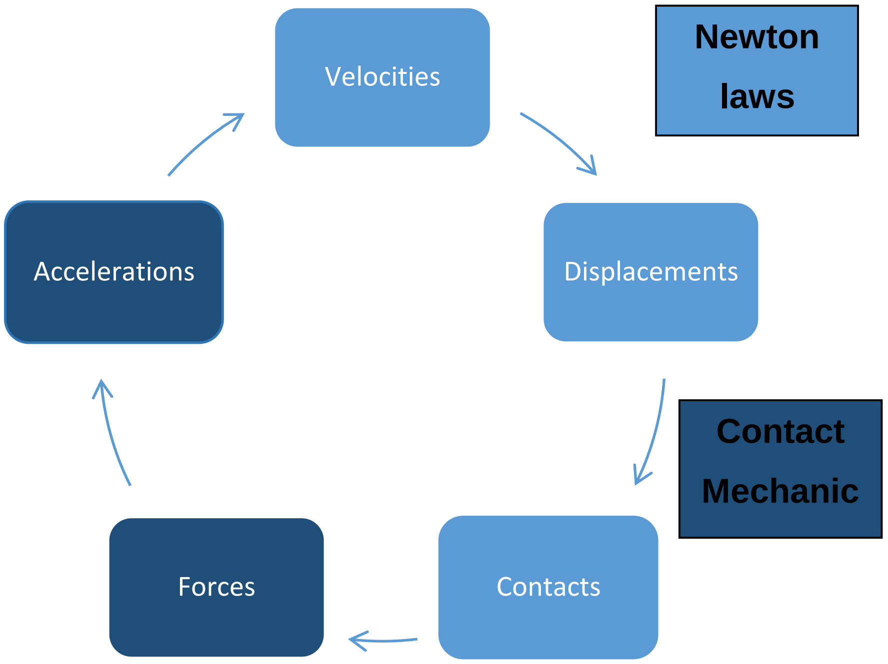



*Figure 2.12 DEM Main Principle*

Discrete Element Method (DEM) can be precisely identified as a discrete approach having the ability to (i) numerically calculate finite particle displacements and rotations and to (ii) automatically perform contact detection for an assembly of particles.

By using contact detection algorithms and applying suitable contact models, DEM software is capable of calculating forces acting on particles. Accelerations, velocities and positions are then computed using Newton's laws of motion and numerical integration.

Hard-sphere and soft-sphere are two main methods of discrete approach.

In a hard-sphere approach, the interaction forces are assumed to be impulsive and particles only exchange momentum through collision. Forces between particles are not explicitly considered.

Soft-sphere method assumes particles are rigid but small overlap is allowed to represent deformation during contact (as shown in the Figure 2.13). This method is most widely used in the industry.

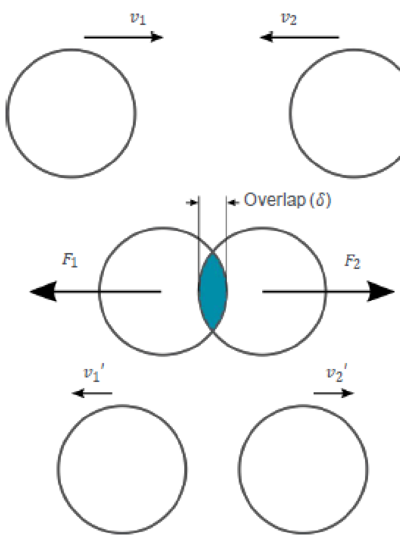



*Figure 2.13 Soft-sphere approach*

Two types of motions are allowed in DEM simulations: translational and rotational. Then Newton's second law is applied to calculate the accelerations, which are then integrated numerically over a time step to update particle velocities and positions.

The translational motion is calculated based on the following equation:

$$m\frac{dv}{dt} = F_g + F_c + F_{nc} \tag{2.5}$$

The rotational motion is calculated based on the following equation:

$$I\frac{d\omega}{dt} = M \tag{2.6}$$

where,

v – Translational velocity of the particle,

m – Mass of the particle,

$F_g$ – Gravitational force acting on the particle,

$F_c$, $F_{nc}$ – Resultant contact and non-contact forces between the particle and surrounding particles or walls,

ω – Angular velocity of the particle,

*I* – Moment of inertia,

M – Resultant contact torque acting on the particle, t – Time.

The acceleration is numerically integrated over a time step to update particles velocity and position.

$$x(t + \Delta t) = x(t) + v(t)\Delta t \tag{2.7}$$

$$v(t + \Delta t) = v(t) + a(t)\Delta t \tag{2.8}$$

Rotational velocities and rotating orientations are updated in similar manner.

Time step choice is one of the critical importance in DEM simulations. It has to be chosen sufficiently small for two reasons: (i) prevent excessive overlaps which result in unrealistically high forces and (ii) avoid effect of disturbance waves (Rayleigh waves). A typical time range is in between 1e-4 and 1e-6 seconds.

Particle movement in the bulk material flow not only affected by its neighboring particle but further particles could propagate by such thing called “disturbance wave”. By choosing small time step in DEM, disturbance waves will be avoided.

The contact models are based on theory of contact mechanics and are mainly developed for spherical contacts. The particle deformation during collisions is modelled as overlap. The contact models related to the amount of overlap to determine magnitude of forces.

The material and interaction properties, such as shear modulus, restitution, and friction coefficients have to be predefined by the user.

The above information has been sourced exclusively from *What is DEM – Theoretical background behind the Discrete Element Method (DEM)* which is provided from EDEM online course.

### 2.2.5 Limitations of DEM

Bharadwaj (21) notes some considerable challenges are still present in the discrete element modelling and the computational capacity is considered the main challenge. As the approach designed to track every single particles position, forces and velocities for each time step, increasing particle number elongate the calculating time also less time step means more calculation time. Additional complexities according to material property (i.e. high coefficient of restitution and friction, realistic particle shape) and geometry (advanced designs with plenty of components).

Another major challenge is a model validation. Slight changes in the material composition such as moisture and clay content affect the level of adhesive stress in materials (19: p.406) If model is not calibrated effectively to the material properties, then there is high risk model is not reflecting actual material flow (3).

# Chapter 3

# Chute Design

## 3.1 Chute Design Fundamentals

This sub-chapter is an actually part of the background research which is ideally should be in the previous chapter. However, it gives a reader possibility to compare and realize the correlation between basic design fundamentals and currently existing transfer chute design, then the current design will be compared to the optimized one in the next chapters.

The material flowing behavior through the chute is a fundamental principle, many unsatisfactory chute designs are produced due to not fully understanding this. As already mentioned earlier the materials leaving the transfer chute important to have same horizontal velocity component with the receiving conveyor belt to minimize the acceleration of the material and so effect reductions in power consumption and belt wear.

Chute designs basically divided into two main concepts (i) inclined chute and (ii) curved chute. These models have to be chosen carefully depending upon bulk material characteristics. For example, if the material is too abrasive and bigger in size curved chutes are not very suitable. It would generate difficulties with the operation due to high friction wear. Combination of this methods are used in some facilities which is often tailored for the conveying system.

As the chosen topic is dealing with the inclined chute design, in the following content flow patterns in the inclined chute will be briefly introduced.

Bulk solids in gravity flow is considered as possible two modes which are varied flow (fast) and uniform flow (slow) (12) but these terms do not correspond exactly to rapid and tranquil flow, used conventionally to describe liquid flows in channel. These two modes differ from each other by their slope angle. For the fast flow inclination angle is greater than the angle of internal friction of the material and for the slow flow inclination angle is in between the angle of repose and the angle of internal friction as can be seen in the Figure 3.1 a and b taken from Roberts and his colleagues (22) research work.

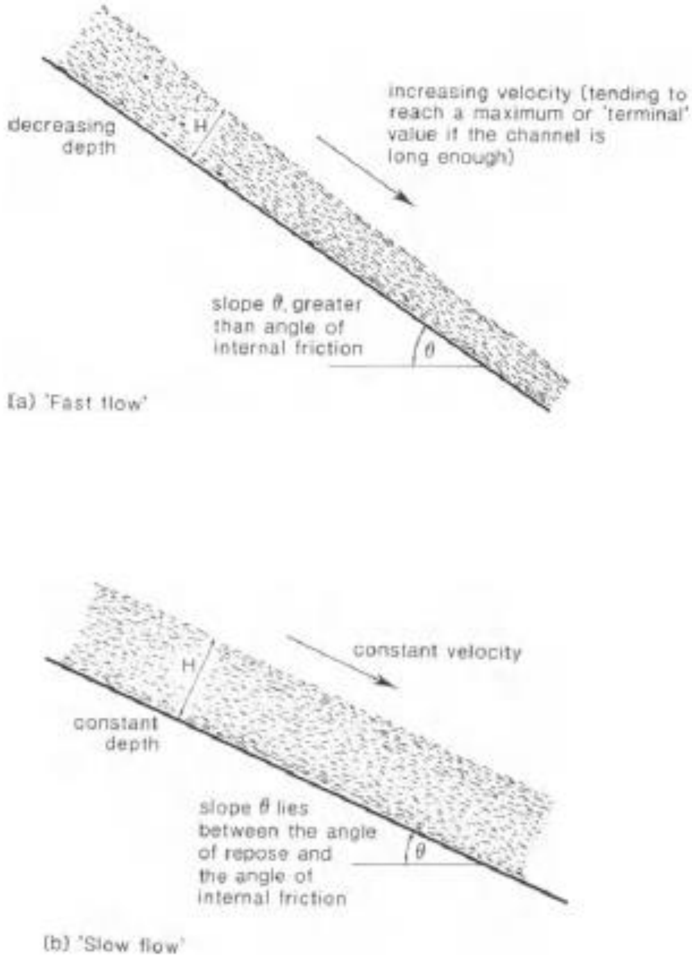



*Figure 3.1 Flow model in straight inclined chute*

If bulk solids are fed into the steeply inclined straight chute, fast flow will occur, the material bed width would decrease till the downward gravity force component equals to the drag forces that applies upward. Flow behave steady when applying forces sums into zero. With the decreasing slope angle, material acceleration would decrease since downward gravity force component decreases. Straight chutes with relatively shallow slope angles act as a slow flow that has more normally distributed (almost constant depth along the pattern) material.

Transfer chute is recommended to have a stable fast profile along its flow pattern, therefore the analytical model of the flow should enable the designer to predict the variation along the chute of velocity and cross-sectional area of the bulk solid streams The main features of the model that set by (22):

- The flow is steady with the material behaving as a continuum
- No drag on the free surface of the flowing bed
- The bulk density is constant throughout the bed

General Free-body Diagram is shown in the Figure 3.2 that illustrates the forces affecting the motion of an element of flowing bulk material.

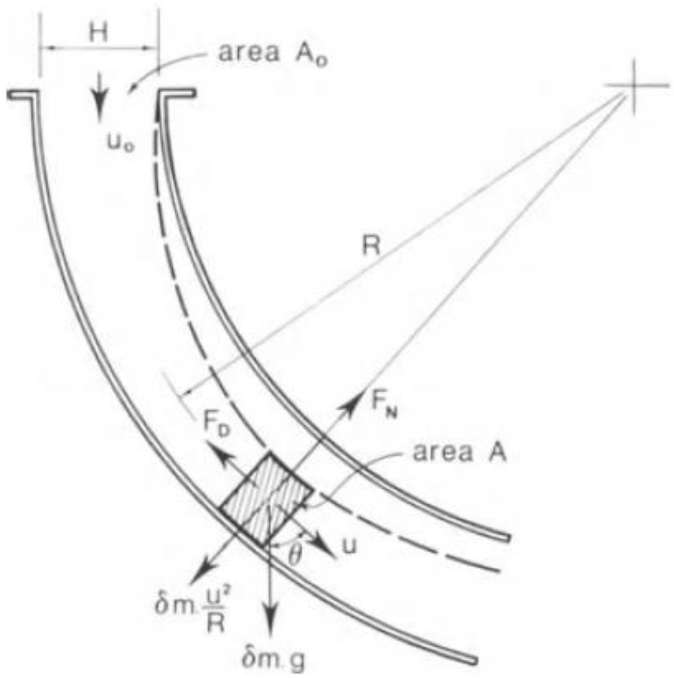



*Figure 3.2 Free-body diagram (Curved chute)*

Assuming the steady flow, continuity equation would have written as:

$$\dot{m}_s = \rho_b A u = constant \tag{3.1}$$

where, A is the cross sectional area of the chute and u is the velocity along the flow trajectory. As already mentioned above, bulk density, $\rho_b$ is a constant throughout the flowing solid stream, equation becomes:

$$A = A_0 \frac{u_0}{u} \tag{3.2}$$

Where, 0 denotes a previous and/or initial position of the bulk flow.

Applying Newton's law, the equation of motion would be:

$$\delta mgCos\theta - F_D = \delta m \frac{du}{dt} \tag{3.3}$$

$\delta$, angle of arc of contact of bulk solid stream in channel. Drag force, $F_D$ is simply the friction force between the particles and the chute inner surface. Therefore, it can be written as:

$$F_D = \mu_E F_N \tag{3.4}$$

where, $\mu_E$ is the effective friction coefficient and the $F_N$ is the normal force acting on the element. Effective friction coefficient is depending on the chute geometry and its stress distribution, it will be described later on.

Referring to the Figure 3.2, the normal force acting on the flowing element of bulk solid is given by:

$$F_N = \delta m(gSin\theta + \frac{u^2}{R}) \tag{3.5}$$

And the drag force equation becomes:

$$F_D = \mu_E \delta m(gSin\theta + \frac{u^2}{R}) \tag{3.6}$$

By substituting drag force equation into the equation of motion (3.3), it becomes:

$$\frac{du}{dt} = g(cos\theta - \mu_E sin\theta) \tag{3.7}$$

Since R (curvature radius) consider as an infinite in the inclined chute, its limit becomes 0 that we can neglect in the equation 3.7.

By applying chain rule:

$$\frac{du}{dt} = u\frac{du}{ds}$$

where, s is the distance along the chute from entering point, equation 3.7 will be changed into:

$$udu = g(cos\theta - \mu_E sin\theta)ds \tag{3.8}$$

After an integration velocity distribution as a function of displacement becomes:

$$u = [u_0^2 + 2gs(cos\theta - \mu_E sin\theta)]^{1/2} \tag{3.9}$$

For a chute with rectangular cross section, taking the pressure distribution to be of the simple form shown in the Figure 3.3, an expression for $\mu_E$ is:

$$\mu_E = \mu_w(1 + k\frac{H}{B}) \tag{3.10}$$

where, $\mu_w$ is wall friction coefficient, k is the ratio of lateral pressure to the major normal pressure at the wall, B is the width of the chute and H is the depth of the following bed.

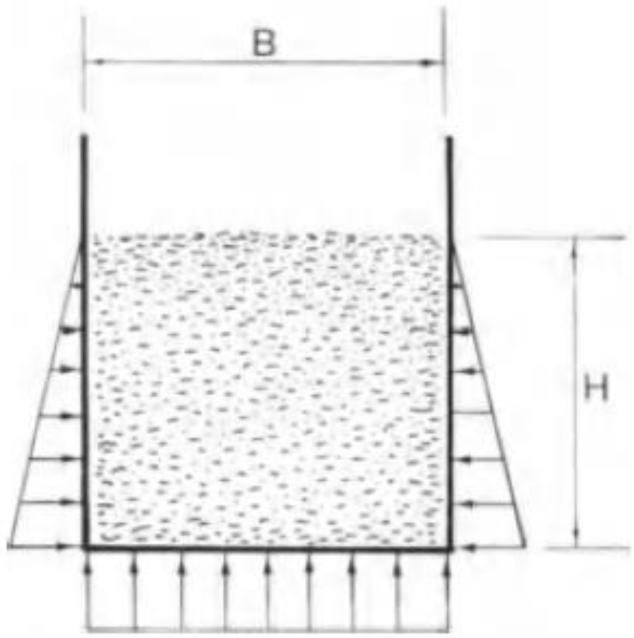



*Figure 3.3 Distributions of pressure on the interior surface of rectangular cross-section*

Experimental work carried out by Roberts and others using a variety of bulk materials showed that a more reliable model is obtained by replacing the coefficient k with the expression:

$$k = k_{E0}(1 + Cu^2) \quad (3.11)$$

where, $k_{E0}$ is the effective linear pressure gradient down the chute wall surface at zero velocity and C is an "irregular stress constant".

Noting H= $(u/u_0)H_0$, equation 3.11 becomes:

$$\mu_E = \mu_w[1 + k_{E0}(\frac{1}{u} + Cu)\frac{u_0 H_0}{B}) \quad (3.12)$$

For a chute of rectangular cross-section shown in Figure 3.4 in a which surcharge is parabolic, the cross-sectional area, A, is given by:

$$A = BH_1 + \frac{B^2 tan\lambda}{\lambda} \quad (3.13)$$

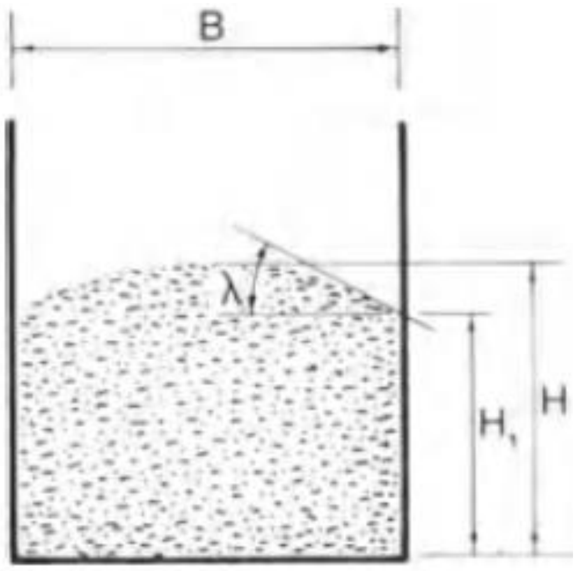



*Figure 3.4 Calculation of cross-sectional area of rectangular shape*

Since

$$H_1 = H - Btan\lambda \quad (3.14)$$

We have

$$H = \frac{A}{B} + \frac{\lambda - 1}{\lambda} Btan\lambda \quad (3.15)$$

For the circular cross-section, again with the parabolic surcharge, the cross-sectional area is:

$$A = \frac{B^2}{4}[tan\lambda\left(\frac{1-cos\delta)}{3}\right) + (\frac{\delta - sin\delta}{2})] \quad (3.16)$$

Where the angle $\delta$ defines the contact perimeter. Also, an expression for the depth of the bed is:

$$H = B\sin\left(\frac{\delta}{2}\right)tan\lambda + \frac{1}{2}B(1 - \cos\frac{\delta}{2}) \quad (3.17)$$

The following general guideline is given by (12) for design of transfer chutes in order to set stable fast flow conditions:

- Define the system requirements in terms of direction and the magnitude of the velocity. Material feeding arrangement must be defined in order to identify over all cross-section dimensions, which would also define mass flow rate and the particle velocity.
- Bulk solid characteristics and mainly friction coefficients must be known from experimental values. Failure of defining such parameters could lead to

inadequate chute design which would also lead to undesired conditions during the operation.

- Equation 3.9 and 3.17 defines longitudinal velocity and the variation in the bed thickness.

All these figures and equations that were mentioned in the previous paragraphs were exclusively taken from research work of (12,22).

# 3.2 Current Chute Design

As informed in the earlier chapter current chute designs causes a high abrasive wear problem on the chute side walls, neck and the bottom end. Mechanics took an action to eliminate this high wearing problem. They attach grips to the side walls and at the valley (which increases the risk of blockage). A current design used conventional inclined chute method using rock box and valley to redirect and centralize the material.

In the Figure 3.5, present transfer chute is shown, including receiving and discharging conveyor belts, head pulley and the skirt. Technical drawing of this transfer chute is attached in the appendix A.

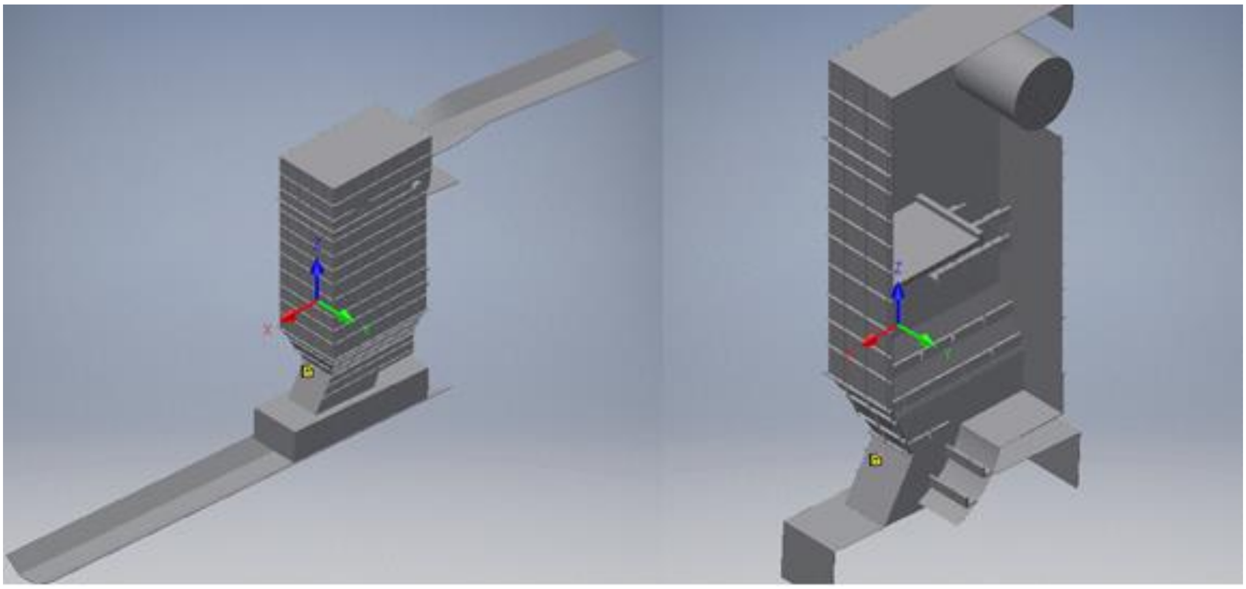


*Figure 3.5a Transfer Chute System* *Figure 3.5b Transfer Chute Half Section View*

Transfer chute is mainly consisting of four main parts, hood, main body (includes rock box), valley, and the discharge end.

## 3.2.1 Hood

Hood is purposed to cover all transferring system, to contain all dust particles inside (in order to avoid dust emission to the environment), to carry pulley and to have an inspection door. This part does not have to be lined by wear resisting material due to there is not any direct contact with the flowing material. The chute hood is shown in the Figure 3.6.

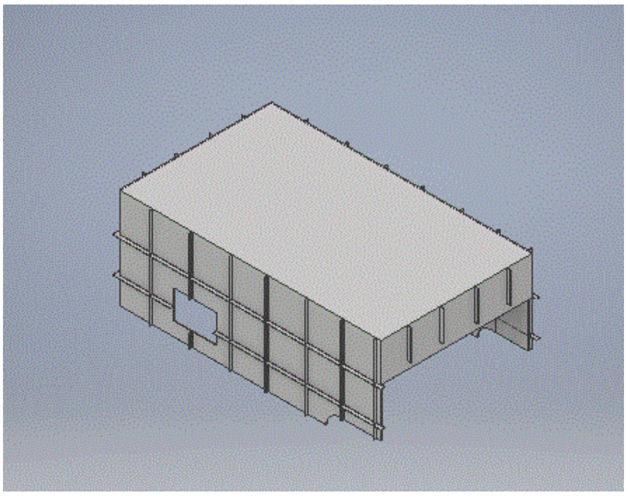


*Figure 3.6 Hood*

This part of the chute does not need any modifications for now. Perhaps some kind of sensors could be installed in this part (i.e. mass flowmeter, vibration sensor, etc.) to maintain reliability of the transfer point.

## 3.2.2 Main Body

The main body is the key part of the chute system due to it contains the most of the flowing material inside, and the rock box is being in here to accumulate the material and change the flow direction at the transfer point. Main body is shown in the Figure 3.7.

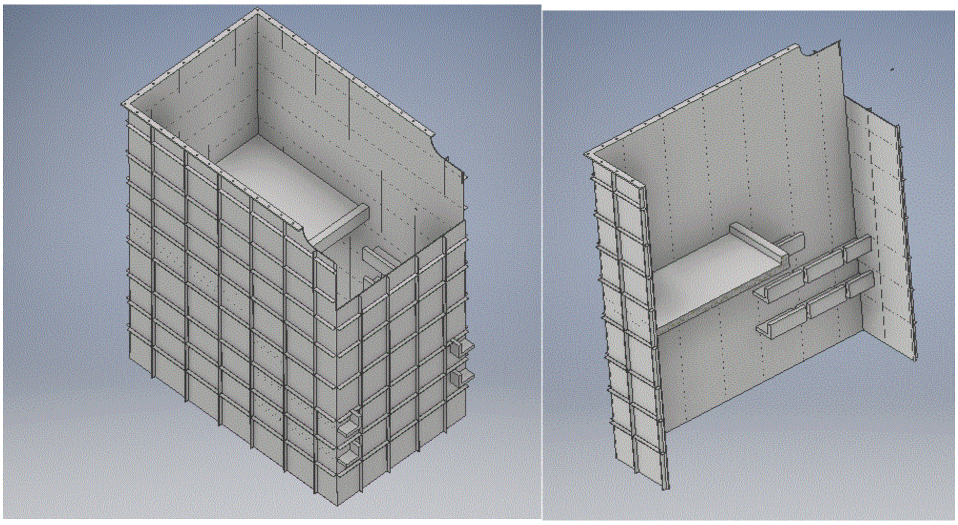


*Figure 3.7a Main Body* *Figure 3.7b Main Body Half Section View*

The main body of the is generally straight box that has material collecting box in the first contact point of material and chute. Accumulated material then act as a deflector which is purposed to redirect the incoming flow. Moreover, main body has to provide centralized gravity fall to the downstream. These side grips show in the figure above aimed to act as a smaller rock box. These small rock boxes collect materials and protect the liner material from repeated material impact. These small rock boxes solution to one problem but unfortunately they are also causing the problem. During the cold climate times, material stuck and freeze in these rock boxes which makes it harder to change the liner plates. This modification is made by OT's engineers based on the error-and-trail method without any specific calculations of ore flowing trajectory. Later in this chapter another possible design mistake in this part will be described.

### 3.2.3 Valley

The valley is one of the critical part of the chute as it wears out quickly and its design purpose is the very important in transferring the material in chute. As seen in the Figure 3.8, chute valley is also modified with the smaller rock boxes to minimize wearing problem. This approach increases the risk of blockage in the chute.

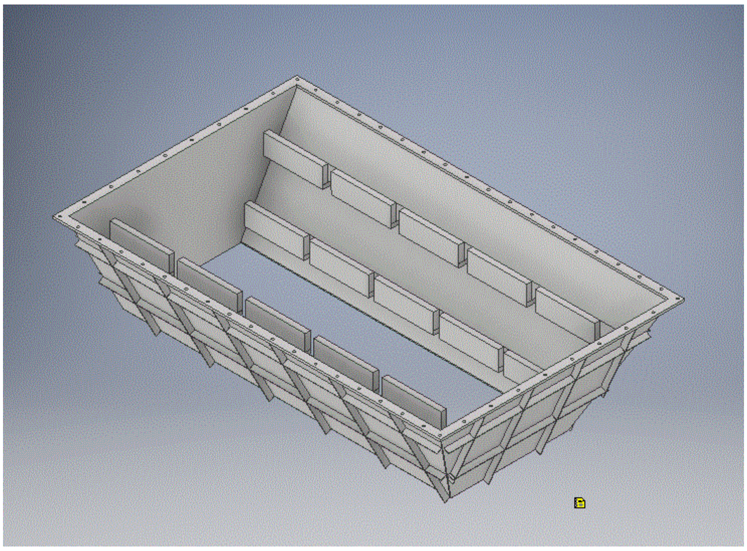


*Figure 3.8 Valley*

According the very simple calculation of continuity minimum cross-sectional area has to be:

$$A = \frac{S\dot{m}}{3600u\rho_b} \tag{3.18}$$

As S is the safety factor which is ranging from 2 to 3, u is the particle velocity (which can be considered as a belt velocity), and the bulk density of the material. Current design is fulfilling the requirement but this modification could lead to another possible problem which would be described in the next sessions.

Current minimum cross-section requirement is 0.74 $m^2$ with 2.5 safety factor, 1750 kg per cubic meter bulk density, 7100 tons per hour throughput and 3.78 meters per second velocity, while its cross-section at the end of the valley (minimum cross-section of current chute) is 3.2 $m^2$.

The valley is generally purposed to direct material just by allowing material to slide it over by providing higher angle than material's angle of repose. In this case, valley has to provide more than 60 degrees in horizontal. Main disadvantage of this flow controlling method is increased wear on the liner plates. Regarding to the company request, this valley is the most problem causing part of this transfer chute.

### 3.2.4 Discharge End

This part of the system is aimed to act as a secondary rock box and the discharge the material to the traveling direction of the receiving belt with optimal horizontal velocity as possible. The same modification is also made in this part of the chute to protect liner plate from direct ore contact as collecting material and increasing ore to ore contact. As shown in the Figure 3.9 discharge end uses two different methods of flow regulation, that are rock box and curved inclination. This part also has to provide the centralized discharge at the downstream to avoid misalignment in the receiving belt.

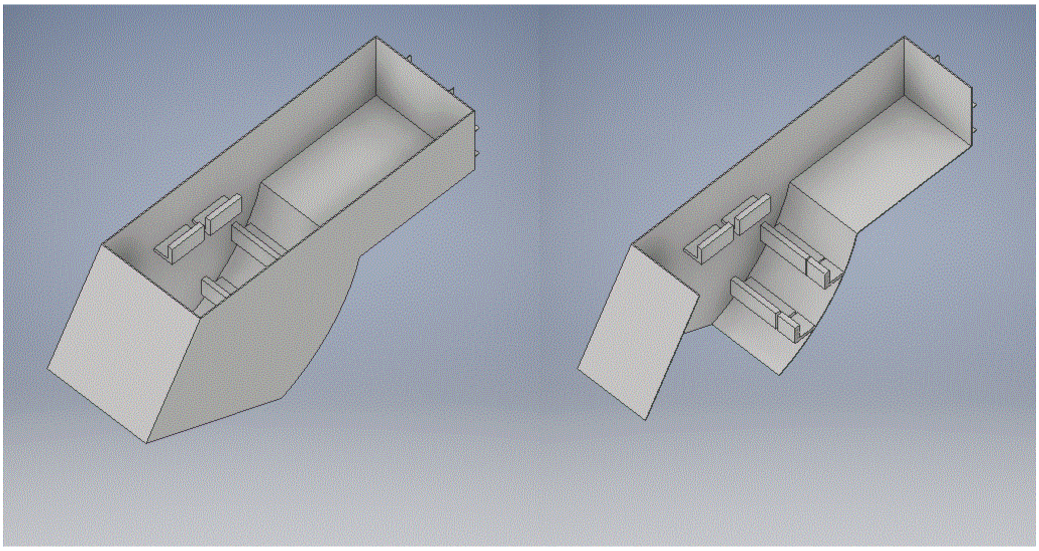


*Figure 3.9a Discharge End* *Figure 3.9b Discharge End Half Section View*

# Chapter 4

# Simulation of Chute Design

Discrete Element Method based simulation is made on EDEM software that is specialized in industrial bulk material simulation. Following chapter will provide main procedure of the simulation, results, comparison and the analysis of the different designs.

## 4.1 Simulation Configuration

In this section, material parameters, geometry and physical behavior of the transfer system that used in simulation would be described.

### 4.1.1 Simulation Geometry

Sets of parameters and factors are required for successful simulation. Material characteristics have to defined correctly and the design has to be exact to achieve realistic results. Chute parts are imported via EDEM and then divided into triangular meshes. Figure 3.5 was used in the discrete simulation which is redrawn from technical drawing provided from the company.

The chute consists of:

- Discharging conveyor belt
- Head pulley
- Hood
- Main body
- Valley
- Discharge end
- Skirt
- Receiving conveyor belt

All this parts are drawn individually and then constrained together.

Small rock boxes attached on the side walls were drawn according to photos taken by OT engineers. There are not in the exact points, but they can fully represent real models.

### 4.1.2 Material Parameters

Three different types of materials are used in this DEM simulation. Copper ore, HARDOX 500 and rubber materials are used to simulate model characteristics. Poisson's ratio, shear strength, density and work functions are necessary to be known. In the Table 4.1 and Table 4.2 materials characteristics and their interaction behaviors are shown.

| Material | Poisson's ratio | Shear Strength (Pa) | Density (kg/m$^3$) | Work Function (eV) |
|---|---|---|---|---|
| Copper Ore | 0.33 | 4.6e+10 | 8900 | 4.8 |
| HARDOX 500 | 0.3 | 8e+10 | 8000 | 4.7 |
| Rubber | 0.5 | 2e+7 | 2200 | 0 |

*Table 4.1 Material Property*

| Material | Copper Ore | | |
|---|---|---|---|
| | Coefficient of restitution | Coefficient of static friction | Coefficient of rolling friction |
| Copper Ore | 0.75 | 0.32 | 0.2 |
| HARDOX 500 | 0.5 | 0.5 | 0.01 |
| Rubber | 0.3 | 0.4 | 0.01 |

*Table 4.2 Material Interaction*

For the copper ore properties are taken from Generic EDEM Material Database, including material shape and size distribution. Some assumptions are made and all material values taken from other source instead of using ore OT ore properties due to lack of information.

In the figure 4.1, particle shape is shown, it is simply triangular which consists of 3 overlapping spheres. Among all 3D shapes, spheres require the simplest and most efficient method of contact detection which significantly decreases simulation time. Real life particle shape (irregular shape) is important to modelling bulk material behavior (i.e. mechanical interlocking), hence combination of spheres forms irregular shapes. There are different approaches like Polyhedrons and Continuous super quadratic function, but multi-sphere method is advantageous that provides an approximation to actual irregularities while maintaining the computational efficiency and accuracy of spheres. More precise models are usually computationally expensive or even impossible to achieve and it is not really necessary to model bulk material behavior for some cases.

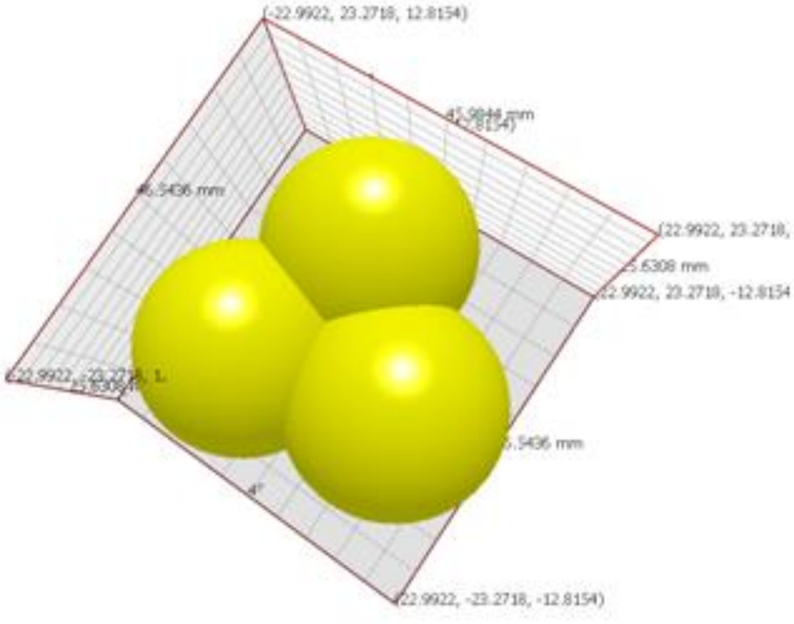



*Figure 4.1 Copper Ore Particle Shape*

In the Figure 4.2, real life copper ore taken from mine site is shown. The ore has 60 degrees of angle of repose and surcharge angle is 5 degrees according to company report.

*Figure 4.2 Real life Copper Ore Shape*

Particle size distribution is shown in the graph below as a histogram. The most of the particles are in between 89 to 95 mm of diameter.

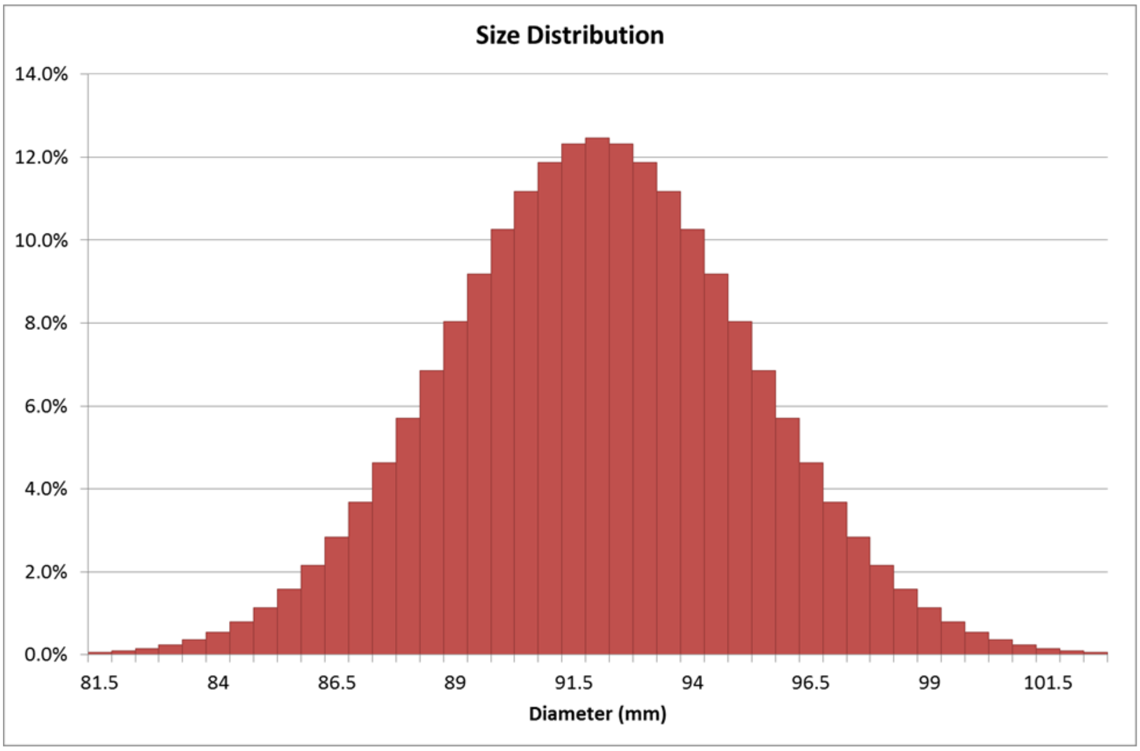



*Figure 4.3 Particle Size Distribution*

HARDOX 500 is an abrasive resistant plate with hardness of 500 HBW, intended for applications where demands are imposed on abrasion resistance. This material is mainly used in processing plants, including crushers, sieves, feeders, skips, conveyors, buckets, etc. Steel plate composes of Carbon, Silicon, Manganese, Phosphorous, Sulfur, Chromium, Nickel, Molybdenum and Boron.

In the simulation, all geometry materials are indicated as a HARDOX 500 except pulley, discharging and receiving conveyor. This plates at the high friction zones have to be replaced once in a four week. In the Figure 4.4 normal plate and worn out plate is shown.

*Figure 4.4a Normal Plate* *Figure 4.4b Worn out Plate*

## 4.1.3 Simulation Parameters

For the excellence of discrete element simulation, following parameters has to be set:

- Contact Model
- Moving Planes
- Time step
- Particle generation

For this bachelor work, Hertz-Mindlin with JKR contact model is used to simulate ore to ore contact, ore to HARDOX 500 contact and ore to rubber contact. Hertz-Mindlin contact force model is a no-slip model used for modeling contact between particles. It is a variant of the non-linear spring dashpot contact model based on the Hertz-Mendlin contact theory. The forces between two particles are defined as combination normal and tangential forces at the contact point. One can say it is a fully elastic, but when it combines with JKR (refer to Johnson-Kendall-Roberts), it considers adhesion in the contact zones.

Particle generation has to meet system requirement which is 1980 kg/s (7100 t/h). Therefore, 990 particles are being generated in every second. For the first simulation (current design simulation) 15840 particles have to be generated. Particle generator is defined as a virtual quadratic surface (indicated as a green in Figure 4.5) that is placed on the discharging conveyor belt.

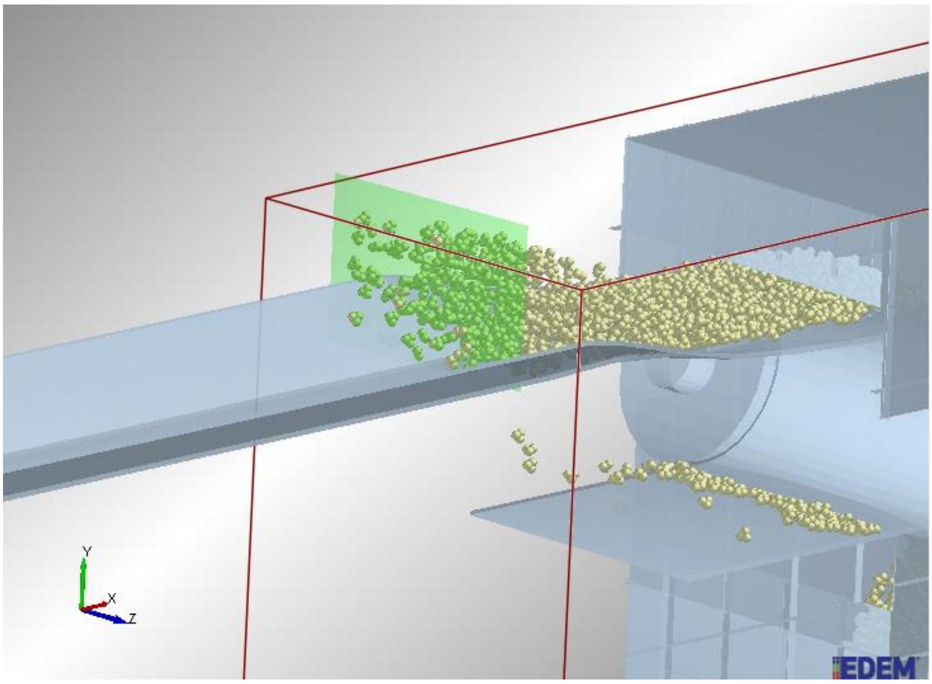



*Figure 4.5 Particle Generator*

To let the particle being carried by conveyor belts, discharge and receiving conveyor belts are defined as a moving plane in horizontal direction with speed 3.78 m/s. Other parts of this system is stationary.

Time step is a main importance in the DEM simulation. It has to sufficiently small to avoid excessive overlaps which leads to unrealistically high forces and to prevent effects of Rayleigh wave that is described in the introductory chapter. Simulation often requires a time step in the range $10^{-4}$ and $10^{-6}$ seconds.

Rayleigh time step is defined as equation below:

$$T_R = \frac{\pi R\left(\frac{\rho}{G}\right)^{12}}{0.1631\upsilon+0.8766} \tag{4.1}$$

where, R is particle radius, ρ is density (not bulk density), G is shear modulus, and $\upsilon$ is Poisson's ratio of the particle.

Simulation time step has to be smaller than Rayleigh time step, otherwise way further particles could affect and disturb another particle. Rayleigh time step is calculated as 4.05e-5 second for both design simulations. Current design simulation set simulation time step as 20% of Rayleigh time step which is 8.1e-6 seconds with total 1.97e+6 iterations.

Simulation grids are defined by smallest radius of 0.0273 m and cell is 10R (0.273 m) with 20920 number of cells.

## 4.2 Simulation Results and Analyzation

This session will describe total results from current design simulation.  Acting forces and flow behaviors are would be explained in this sub-chapter.

Currently operating transfer chute CVB001 is simulated by Discrete Element Modelling software. Parameters and material constants are explained in the previous sub-chapter.

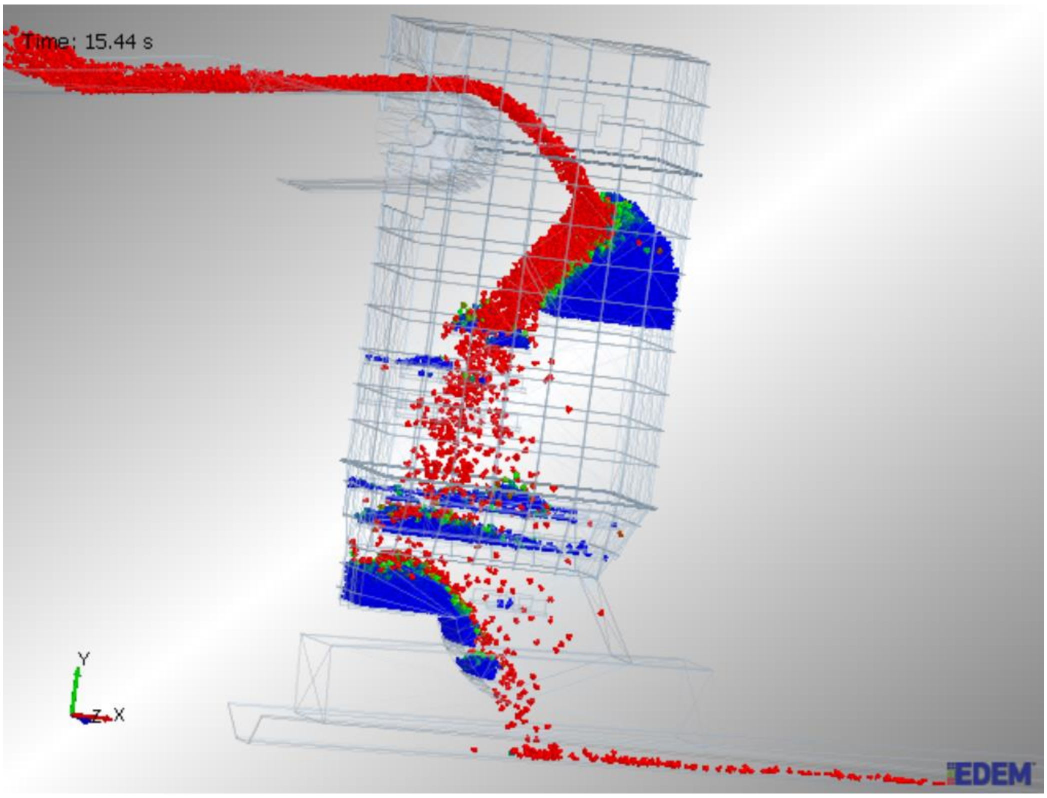



*Figure 4.5 Flow Pattern Along Inside the Chute*

Red color refers to high velocity particles, while green refers to moderate velocity and blue refers to low velocity profiles.

As seen from Figure 4.5 rock box is filled correctly with the bulk material also the discharge end. According to simulation result chute does not experience blockage and spillage in it. Moreover, side rock boxes collect materials in it, as it seems blue in the side walls that indicates not any movement is occurring.

From the simulation results, the rock box is placed in the right place as it seen in the Figure 4.6. Ore collide with the chute at the back edge of rock box, which is an efficient way of contact. If rock box was placed little bit higher or lower, ore will first contact chute wall or in the middle of the tock box which is not desired at all.

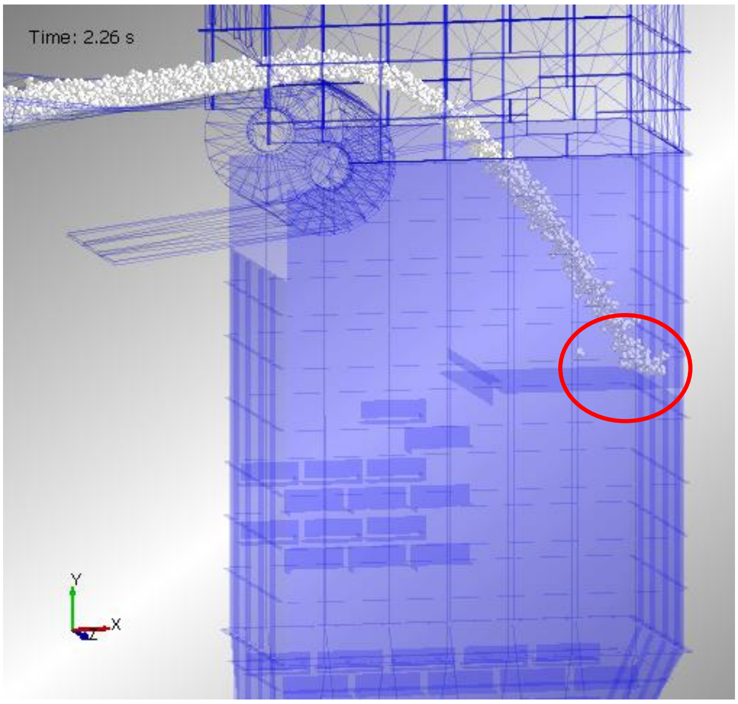



*Figure 4.6 First Contact of Chute and Copper Ore*

After rock box is fully filled with the ore materials it starts to fall to the downstream, while ore is falling some of it drop into the side rock boxes also into the rock boxes at the valley (shown in Figure 4.7).

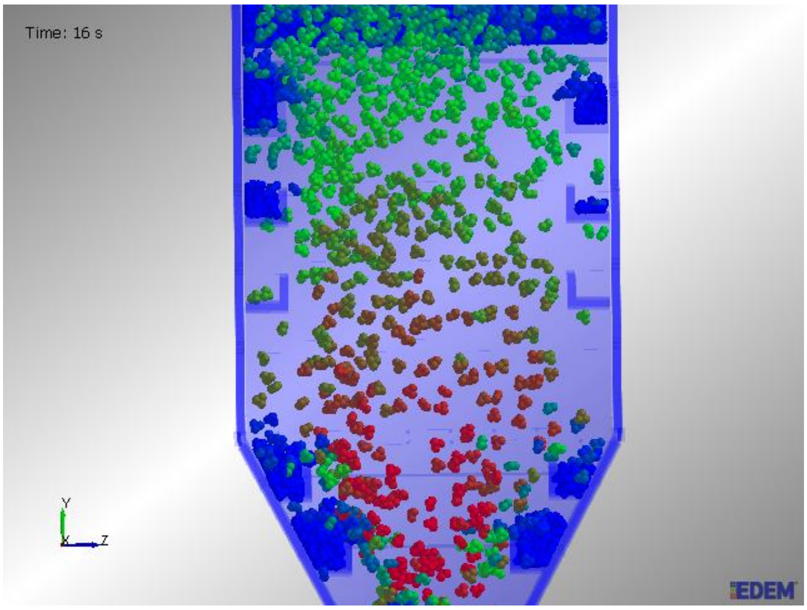



Figure 4.7 Chute End View – Side Rock Boxes

However, some them is not necessary to be attached. As one can see, the third rock boxes from the top are not filled with the material due to upper rock boxes block the ore falling pattern.

The simulation run in total 16 seconds and 15652 particles (shown graphically in the Figure 4.8) were generated and simulated. The simulation has to run more than 30 seconds to observe flow behavior at upper and lower conveyor belt is synchronized. At the 16 seconds rock boxes did not filled fully, hence downstream conveys less material than the upstream.

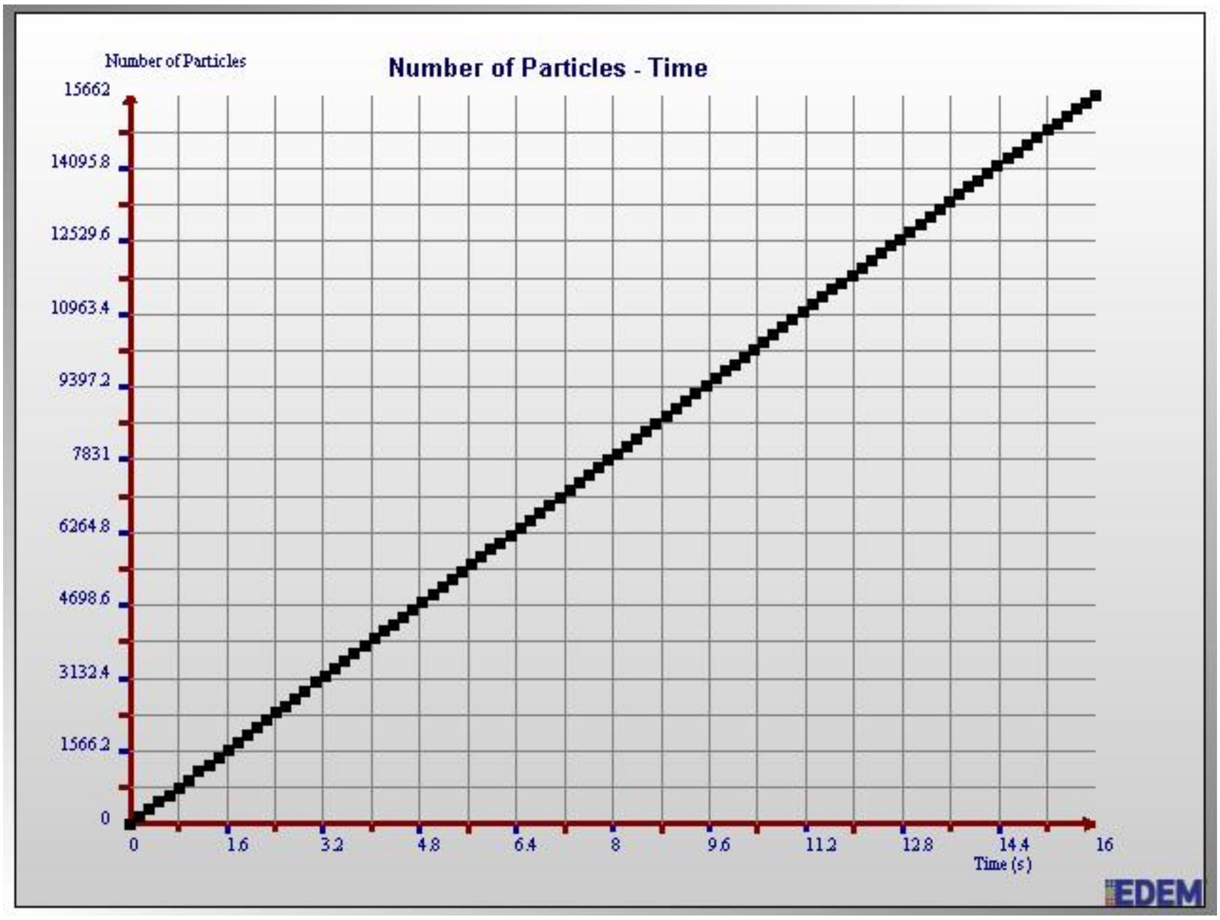



*Figure 4.8 Number of Particles vs. Time*

Force magnitude was calculated on the main parts of the chute body including chute main body, chute valley and chute discharge end. Figure 4.9-11 show total magnitude force actin on the different parts of the chute.

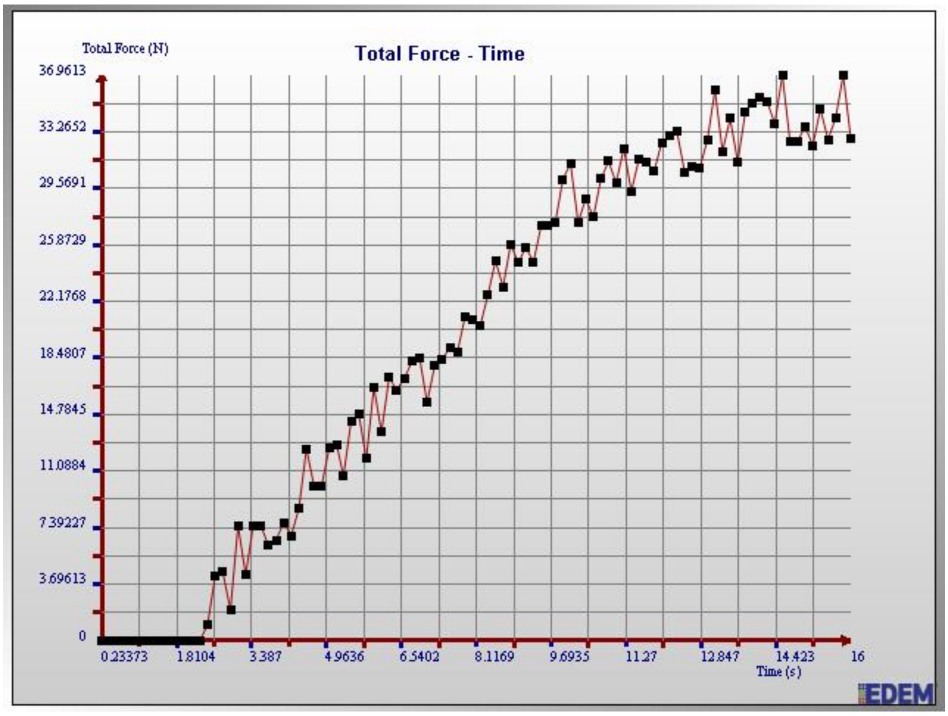



*Figure 4.9 Total Force vs. Time on Middle Part of the Chute*

The middle part of the chute start experiencing contact force from 2 seconds, while material is being conveyed and falls from 0 to 2 seconds. Force is linearly increasing due to particles are being generated continuously hitting the chute. This graphic illustrates acting force at the very specific time interval that becomes constant after sometime.

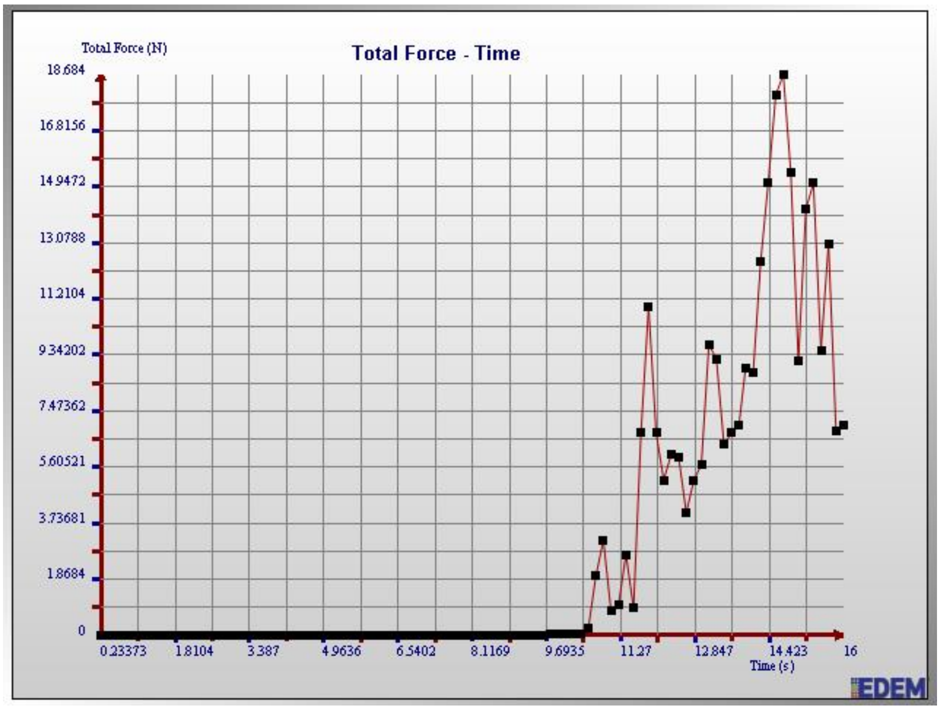



*Figure 4.10 Total Force vs. Time on Valley of the Chute*

Graphic shown in Figure 4.10 represents total force acting on the valley as time goes. As one can see from the graph, ores start hitting the valley from approximately 10 seconds. Till 10 seconds ore is being conveyed and accumulated in the rock box.

This graph has more ups and downs comparing to the previous one due to some particles are hitting the valley while some particles directly dumps into the discharge end box.

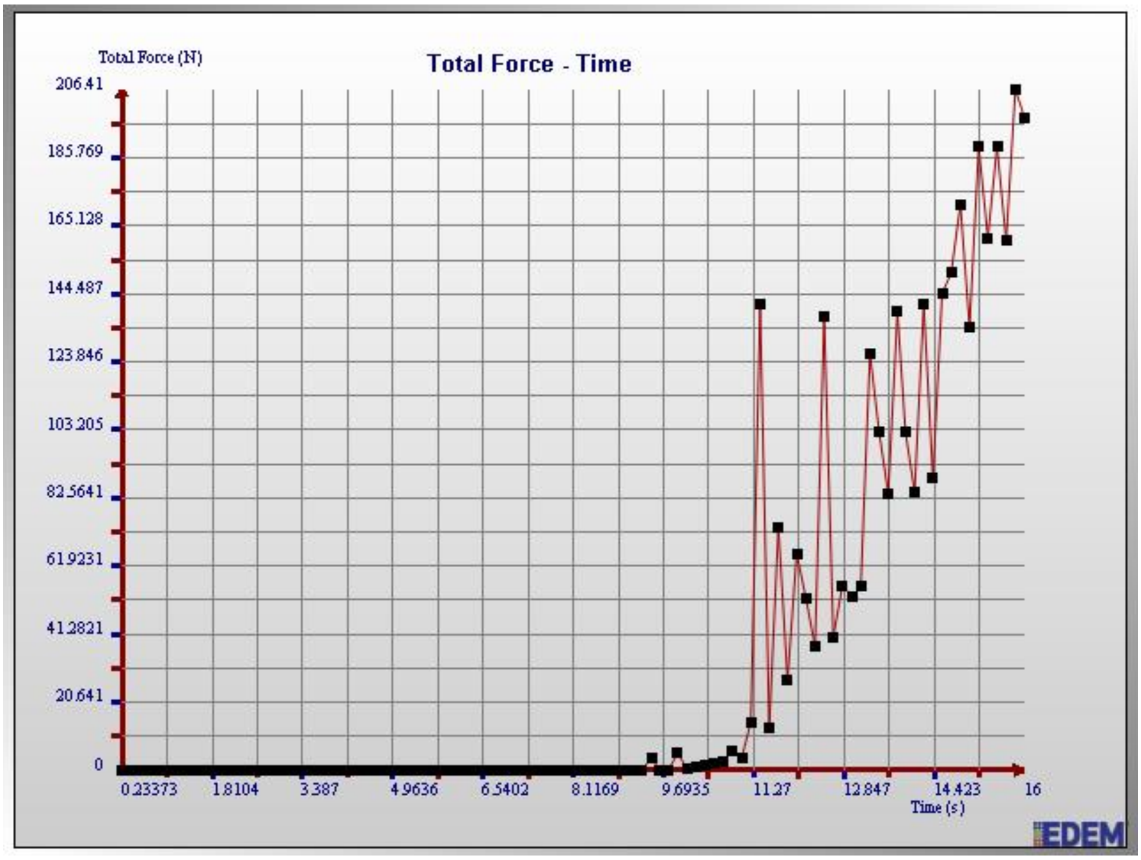



*Figure 4.11 Total Force vs. Time on Discharge End of the Chute*

Ore particles starts hitting the discharge end of the chute from approximately 10 seconds (as illustrated in the Figure 4.11). Comparing with previous graphs this part experienced more force due to it is located bottom of the chute, which means falling ores from height creates more forces on this part. This graph is zig zag shaped due to particles hitting different parts of the chute, which is different in vertical dimensions.

Sum of the total force acting on the different parts are provided in Appendix B as a histogram.

Particle velocity distribution along the material plow pattern is shown in the Figure 4.12.

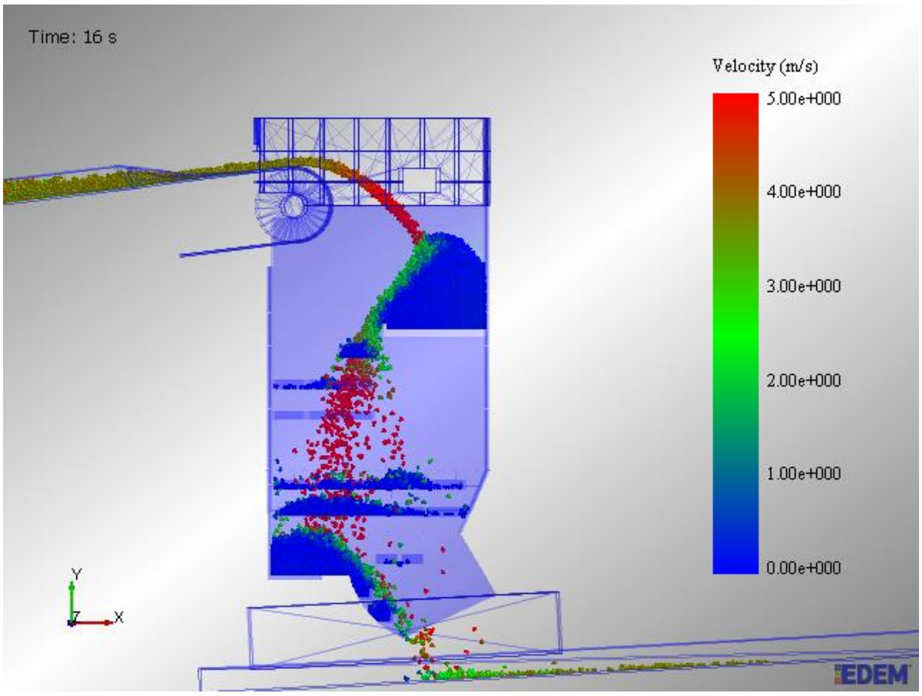



*Figure 4.12 Particle Velocity Along the Chute*

As one can see the velocity profile is in a normal range at the point of contacts which could be less than it in the worst cases. Hence, the particles that is sliding over the other particles are illustrated in the green color, it indicates blocking would not occur in the system. However, some particles are falling directly to the receiving belt. It would be closely shown in the Figure 4.13.

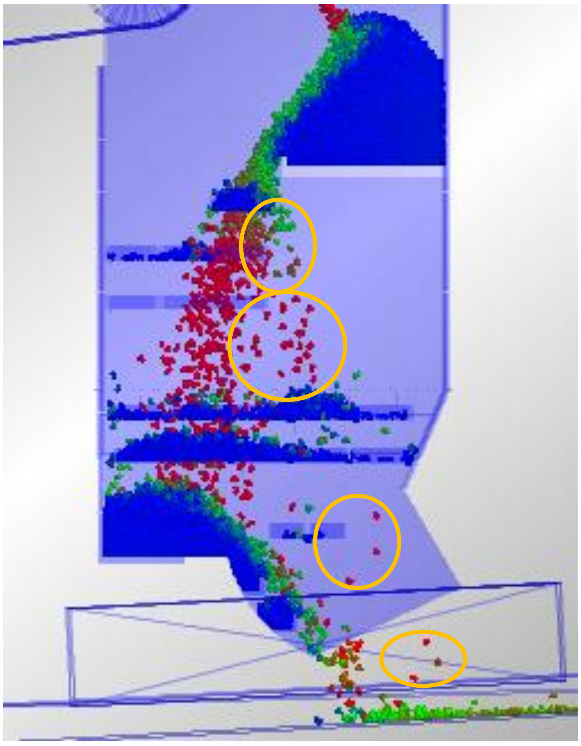


*Figure 4.13 Irregularly Falling Particles*

These particles are hitting the side rock boxes (in main body and valley) and deflected into the reverse direction which leads them to directly fall into the receiving belt. These effect would harm to the receiving conveyor belt as particles hitting it with high forces and would increase the belt wear. Furthermore, centralization would be ruined with this malfunction. Non-central loading could lead to catastrophic damage in the conveyor belt as it misaligns and fully destroyed.

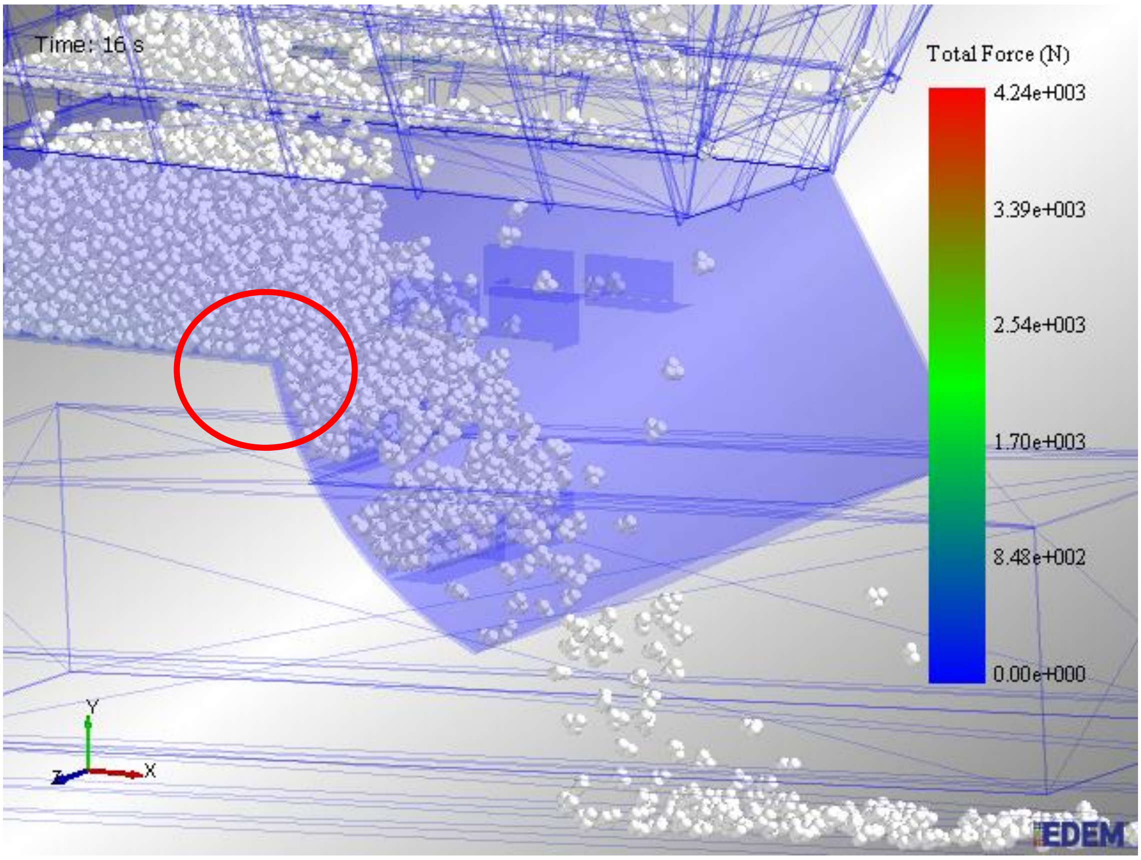



*Figure 4.14 Discharge End – Back Edge Damage*

Damage in the back edge of discharge end is being caused by high sliding friction along it. This part of the chute acts like rock box with curved sliding surface that allows the particle accelerate before discharged into the conveyor belt. Hence, every particles passing through the chute has to slide through this part.

Simple solution could be applied for this malfunction, just by adding lip liner (shown in the Figure 4.15). Lip liner is used in the upper rock box. Correctly designed lip liner would let this edge avoid from direct contact.

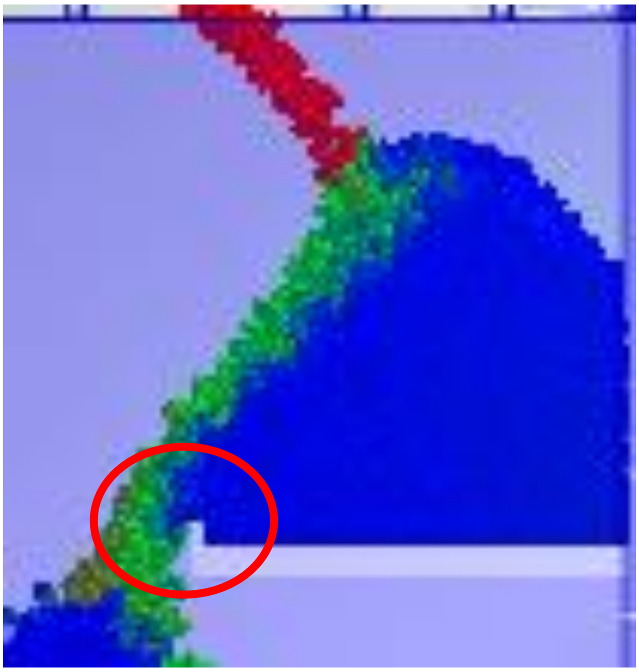


*Figure 4.15 Lip Liner*

## 4.3 Suggested Design Modification

Design optimization has to be made on the current chute design to improve its lifetime and to decrease housekeeping time. As described in the early chapters, high abrasive wear occurs at the valley, side walls and the back edge of the discharge end part. OT engineer's optimization does not satisfy their demand; the company wants to decrease down time from once in a four week to once in an eight week, which is a very difficult task to achieve with cost effective solutions.

A simple modification on the chute valley is made to decrease sliding wall friction. Instead of using valley, different kind of rock boxes are set on the side walls which is changed a little bit current geometry. Present valley geometry is trapezoid that has an angle steep enough to provide gravitationally flow the material. Modified valley would allow material slide on the material (not on the liner plate). Figure 4.16 illustrates this simple change made by CAD tool.

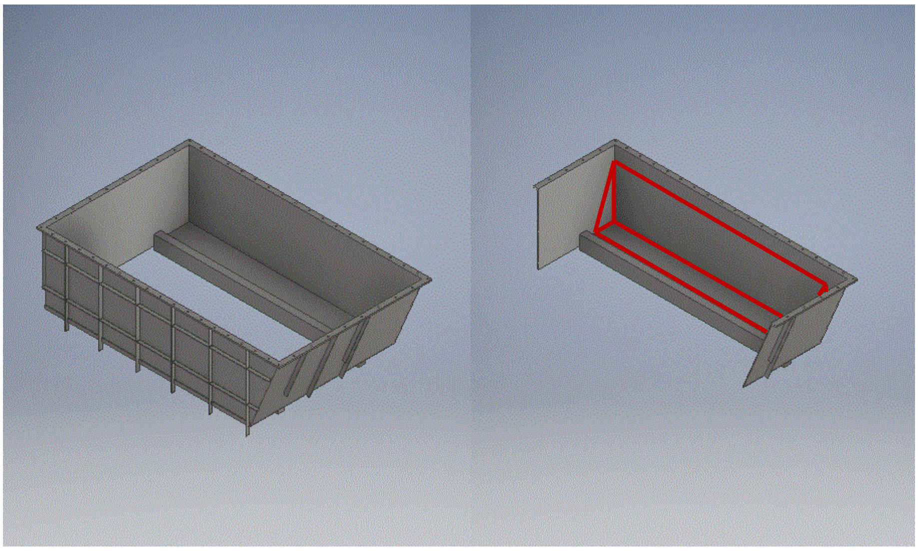


*Figure 4.16a Modified Valley Design  Figure 4.16b Modified Valley Design Half Section*

This enhancement increases ore to ore contact while avoiding ore to chute contact. Lip liners are installed in order to accumulate more material in the rock box but also to avoid undesired flow of the particles.

Bulk material would fill a space that is indicated as a red frame in the Figure 4.16. Outer layer that created by material itself would reduce the contact force that the chute valley is currently experiencing.

This boxes also could include some initial horizontal angles like the one in Figure 4.17 taken from technical Adi Frittela's current work in South Africa (10).

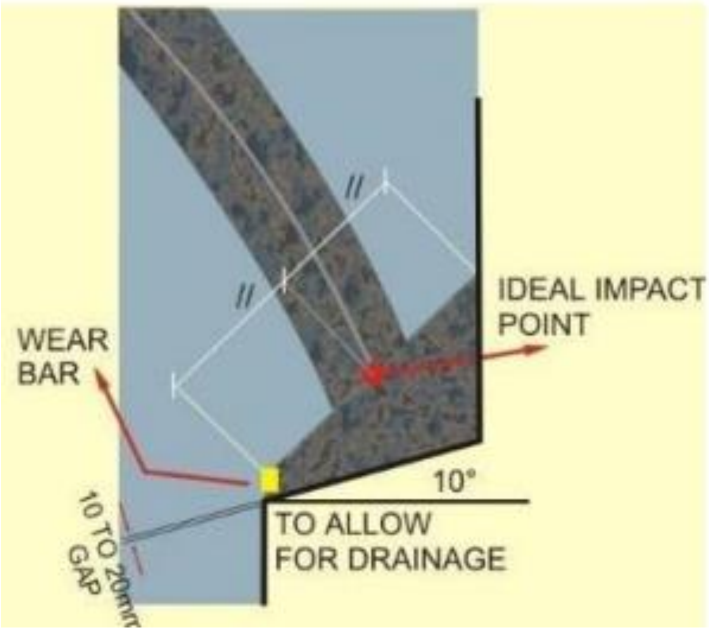



*Figure 4.17 Initial Horizontal Angle*

As mentioned in the literature review section, the valley should provide at least 5 more degrees than the material angle of repose. To increase flow ability of previously mentioned modification, horizontal angle could be set.

By reviewing the current design upper box (shown in Figure 4.18) is placed in the right elevation but it is not sufficiently long enough to discharge material without creating undesired particle flow that leads particles fall into the different sections of the chute. There are simply two possible solutions to overcome this problem. The first one is to elongate the upper rock box by 200 mm to exactly shower on the discharge end box.

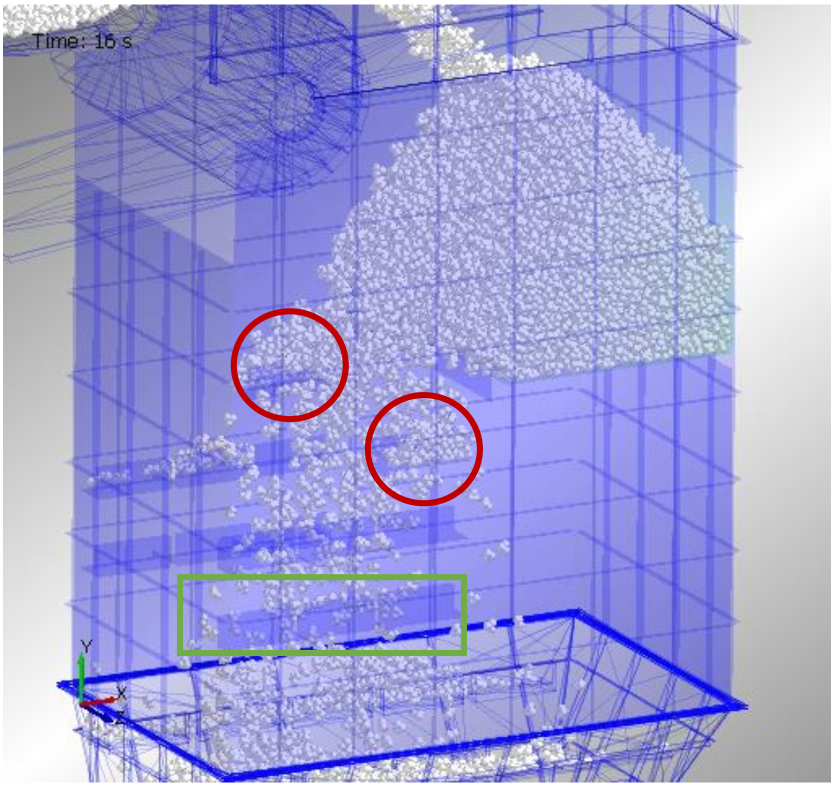



*Figure 4.18 Rock box*

Another possibility is to rearrange side rock boxes. Red circled rock boxes in the Figure 4.18, they are creating great disturbance in the flow pattern, as deflecting particles into the another direction. Moreover, as mentioned in the result section some of the rock boxes (indicates as green color in the Figure 4.18) attached in inadequate location due to upper boxes block the flow pattern. Therefore, these side rock boxes should be placed like a stair and the red color indicated rock boxes should be placed little bit further (in direction of flow pattern) than the main rock box.

# Chapter 5

# Conclusion

A background investigation was conducted into bulk material properties, some of the common issues in the transfer chute and current designing methods to resolve those issues. Moreover, chute design fundamentals, including numerical analysis of velocity distribution and flow characteristics have been studied.

Current chute was redrawn in 3D version by using Autodesk Inventor to simulate ore flow characteristics. Discrete Element simulation was made EDEM software, as a result some of the design issues were detected. Initial parameter setting for the simulation configuration is used various sources that is available on the markets. However, real material is not tested and calibrated due to technological limits and lack of information, but it will not dramatically change the simulation results as it is investigating design.

Deflection of ore particles into the opposite direction, non-central loading, high sliding wear on the edge of discharge end and inadequate side rock box locations are the problems that detected during the simulation. And corresponding possible solutions are provided in the results and analyzation section.

Design modification in the chute valley section is made to increase flow ability of the bulk material at this part, to reduce abrasive wear in this part and to make the housekeeping process less complicated and more safe.

# Chapter 6

# Further Work

There still further investigations to be carried out to improve the confidence of the chosen chute design. The following work is recommended to resolve some of the issues not yet discovered by this research:

- Further investigations of wearing issue. The material properties have to be exactly known by laboratory test. In this research work the most of the material parameters taken from other source that is not exactly matching with the copper ore being examined. However, the main flow characteristics remain the same but more precise information would be provided with exact material property.
- Another essential piece of work is calibration of the simulation. The ore flow characteristics are not fully calibrated within this work due to unavailability of instruments. During the site visit, it was not allowed to open an inspection door to take a photo that could be used for calibration. Moreover, particles were too big to examine it with the laboratory equipment while it cannot be crushed, hence it cannot represent its original shape.
- Furthermore, simulation has to run at least another ten seconds to deliver full information about transfer chute. Current simulation run till 16 seconds, downstream could not fully synchronized with the upstream due to side rock boxes and discharge end box did not fully filled which means incoming ore particles still have to stay inside the chute. By prediction it has start synchronizing at 20 seconds. The simulation requires high computer capacity due its calculating all interactions, contact forces, accelerations, velocities and displacements of all particles that are being generated. Current simulation took nonstop 8 days to accomplish 16 seconds with time step of 8.4e-6 seconds.
- More design concepts have to be reviewed to get optimal solution. One of them is to give an initial horizontal angle of at least 10 degrees to the previously suggested design modification. Hence, it let the material to flow frequently in the chute and centralizing task of the chute design would be enhanced. Moreover,

simulation should be made with side rock boxes at different locations. Otherwise, they are currently attached in a wrong place that some rock boxes block another and some of them creates undesired particle flow pattern inside the chute which could increase the receiving belt wearing and high impact wears on the chute liners.

- Finally, particles used in this simulation could not fully represent the ores that is being conveyed in the system. This research uses only one particle shape and size to simulate the ore flow but in a real life situation is different. At least 3 different particle sizes have to be applied to the next simulations. However, it would not affect dramatically to the result of the simulation due to the particle being used in the simulation could replace main (and the most) ore particle that is damaging the chute.

# References


1. David Beckley. Belt Conveyor Transfer Chutes - Tips for Designers, Australian Society for Bulk Solids Handling. 2011;
2. American) JP (Anglo. Examples of Good and Bad Chute Design. 2006.
3. Grima AP, Fraser T, Hastie DB. Discrete element modelling : trouble-shooting and optimisation tool for chute design. Beltcon 16. 2011;1–26.
4. Mason A. Improved Transfer Chute Design Using DEM Software to Predict Material Flow Behaviour. 2016.
5. Benjamin, C, Donecker, P, Huque, S & Rozentals J. The Transfer Chute Design Manual for Conveyor Belt Systems, Conveyor Transfer Design Pty Ltd. 2015.
6. CEMA. Belt Conveyors for Bulk Materials, Conveyor Equipment Manufacturers Association, United States of America. 1997.
7. Andrew L. Mular, Doug N. Halbe & Barratt D. Mineral Processing Plant Design, Practice and Control, vol. 2, Society for Mining, Metallurgy, and Exploration. 2002.
8. Arnold P. Bulk solids : storage, flow and handling, 2nd ed. edn. 1980;
9. David S. Tramsfer Chute Design Fundamentals.
10. Frittella A, Smit A. Chute design essentials. South African Inst Mater Handl. 1992;1–29.
11. Khambekar, J, Pittnger, B, Jenike & Johanson, Dandan R& DRS 2015. “Chutes and Suitability”, World Coal, vol. 24. 2015;
12. Woodcock CR, J.S. Mason. Bulk Solids Handling [Internet]. Bulk Solids Handling: Equipment Selection and Operation. 2008. 197-220 p. Available from: http://doi.wiley.com/10.1002/9781444305449
13. Kulinowski P, Eng PD, Kasza P, Eng PD. Properties Bulk Solids. 2014;1–11.
14. Wikipedia. Bulk Density [Internet]. Available from:

https://en.wikipedia.org/wiki/Bulk_density

15. Thermopedia. Void fraction [Internet]. Available from: http://www.thermopedia.com/content/276/

16. McGlinchey D. Bulk Solids Handling: Equipment Selection and Operation. Bulk Solids Handling: Equipment Selection and Operation. 2008. 304 p.

17. Shamlou PA. Handling of Bulk Solids [Internet]. Handling of Bulk Solids. 1988. 20-50 p. Available from: http://www.sciencedirect.com/science/article/pii/B9780407011809500069

18. Wikipedia. Sphericity [Internet]. Available from: https://en.wikipedia.org/wiki/Sphericity

19. Swinderman, T, Marti, AD, Goldbeck, LJ, Marshall D& S. The Practical Resource for Cleaner, Safer, More Productice Dust and Material Control, Fourth edn.

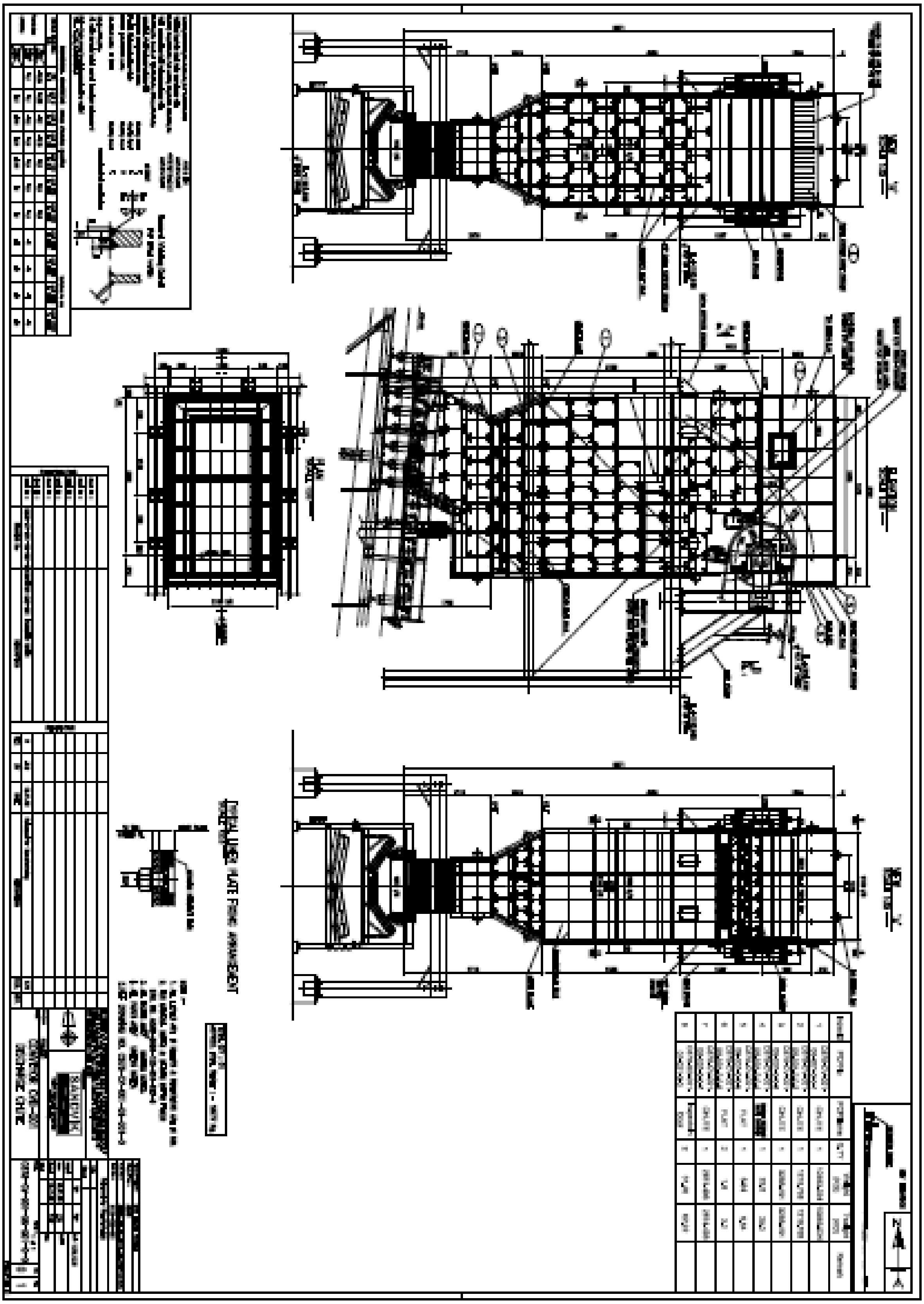
20. Surcharge Angle [Internet]. Available from: https://www.researchgate.net/figure/Angle-of-repose-a-and-angle-of-surcharge-b_fig1_284625481

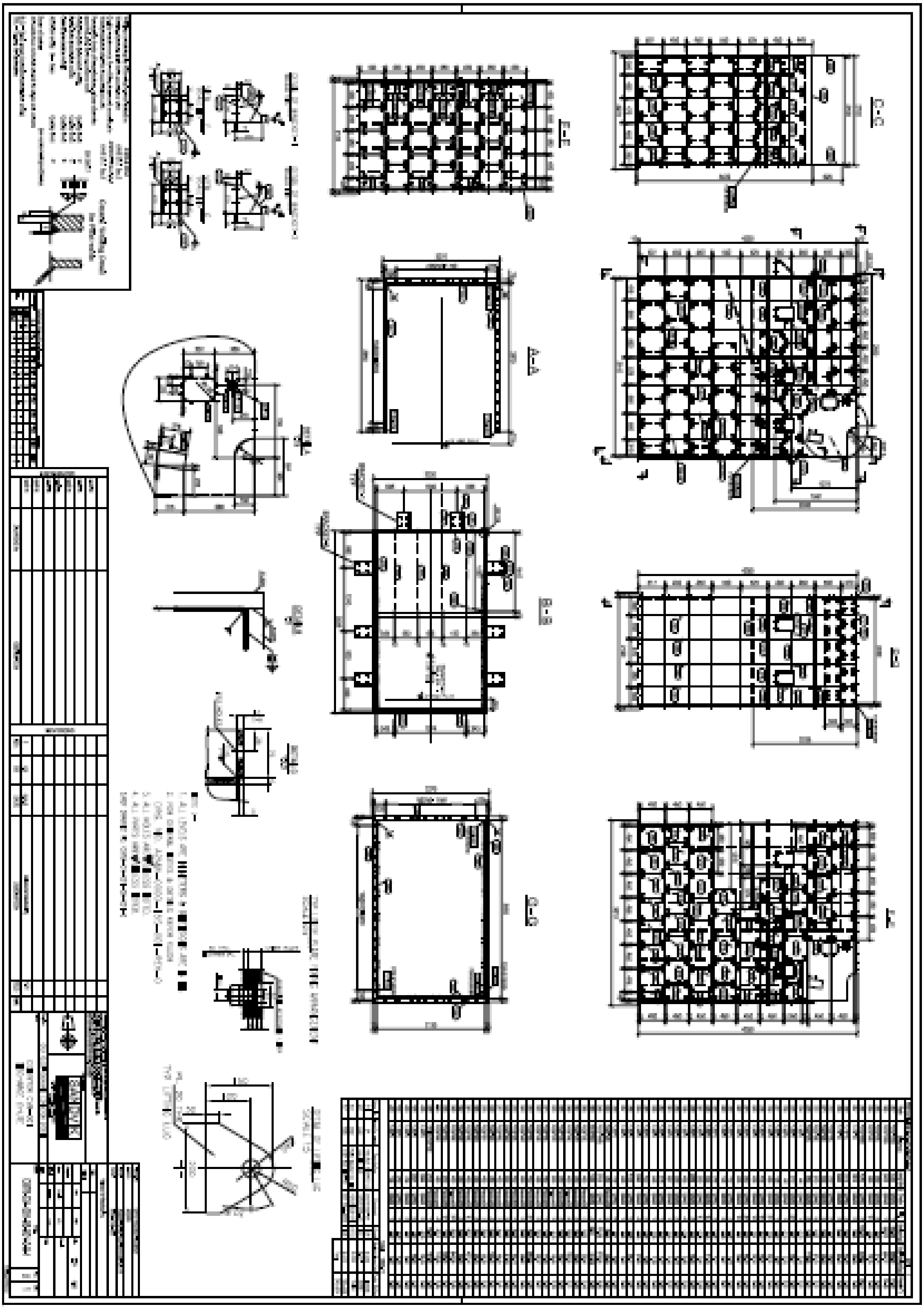
21. Bharadwaj R. Using DEM to solve bulk material handling problems. Chem Eng Prog. 2012;108(9):54–8.

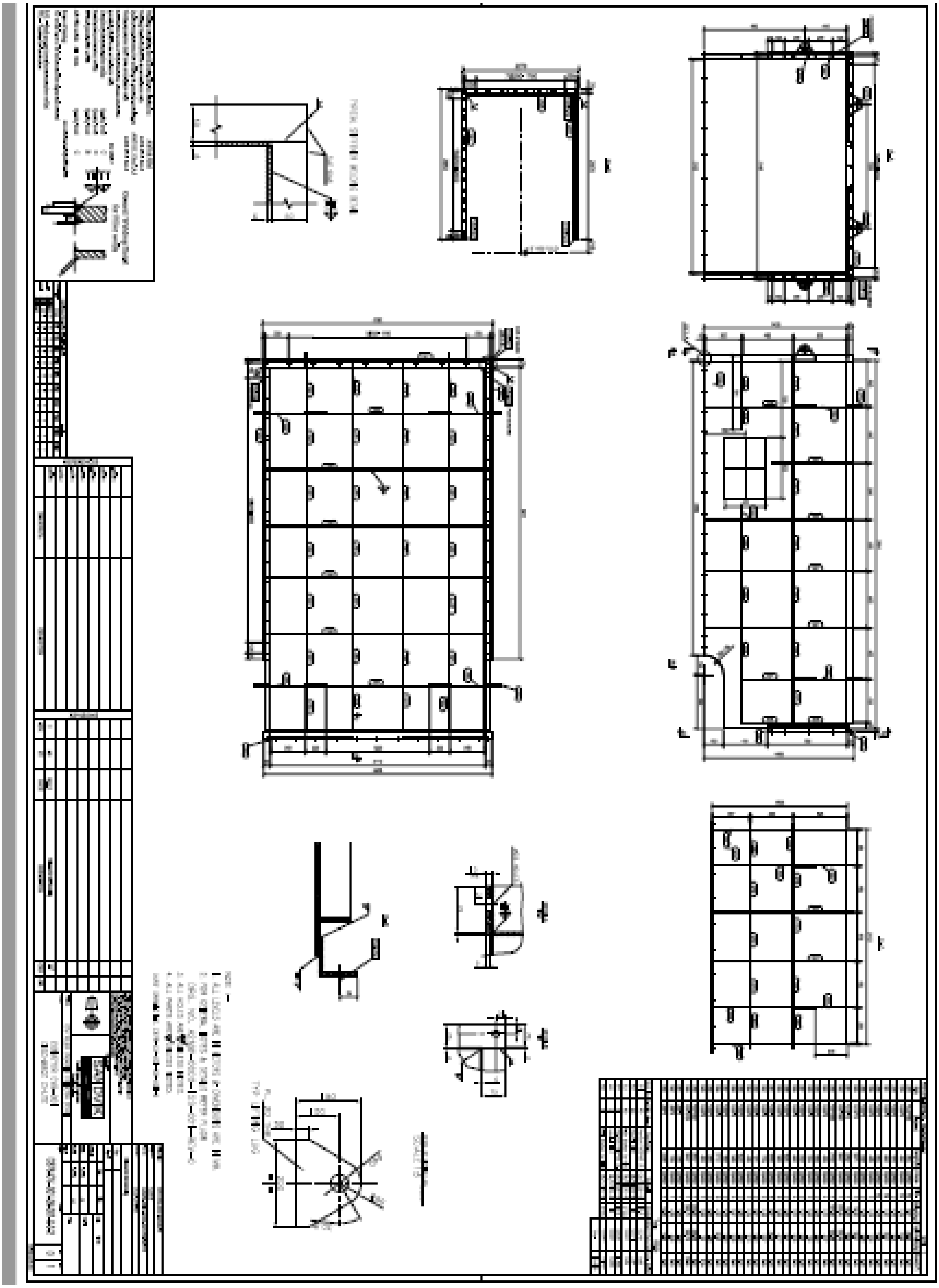
22. Roberts, A.W. and Scott OJ. Flow of bulk solids through transfer chutes of variable geometry and profile. 1981. 715-727 p.

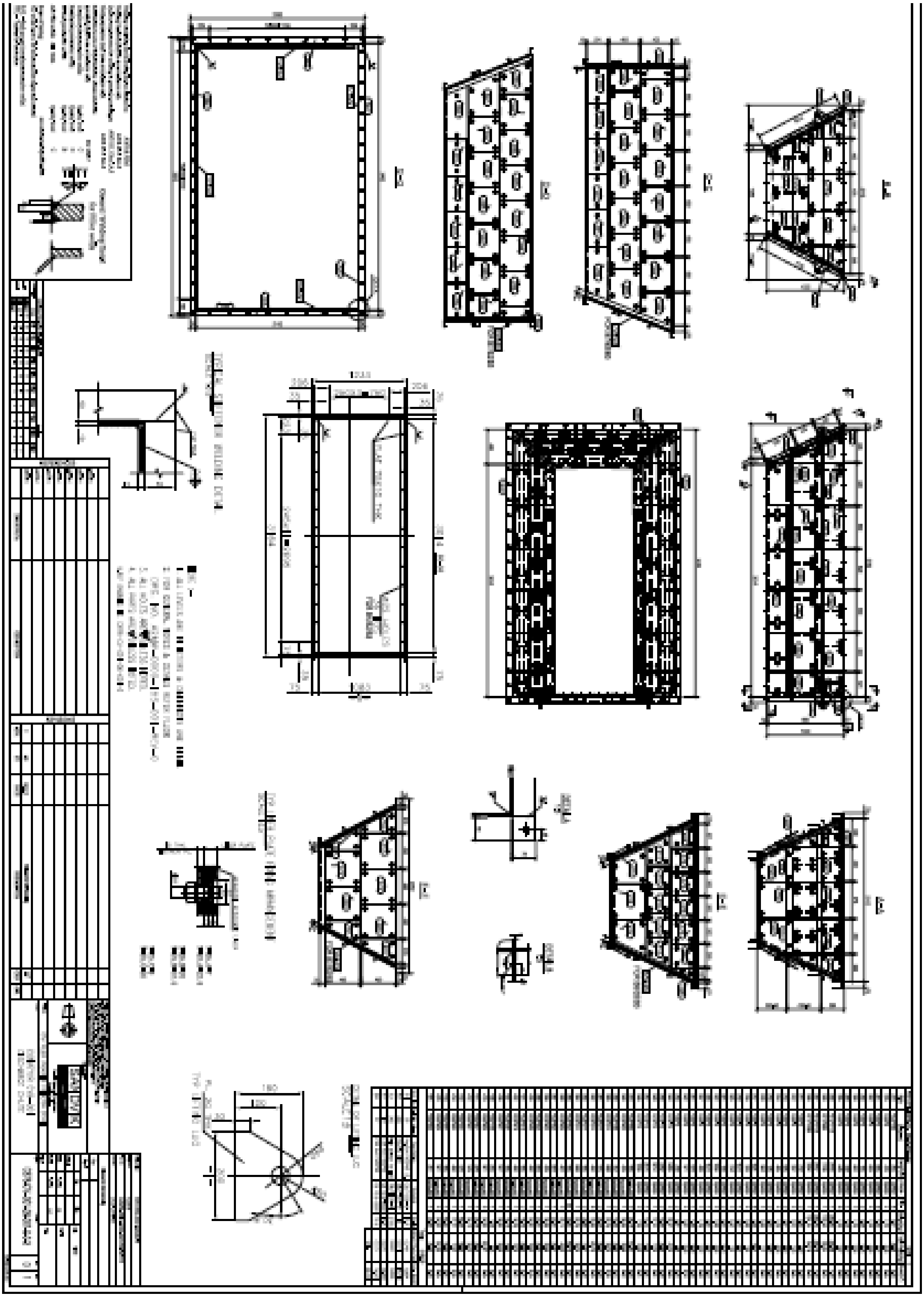
# Appendix A

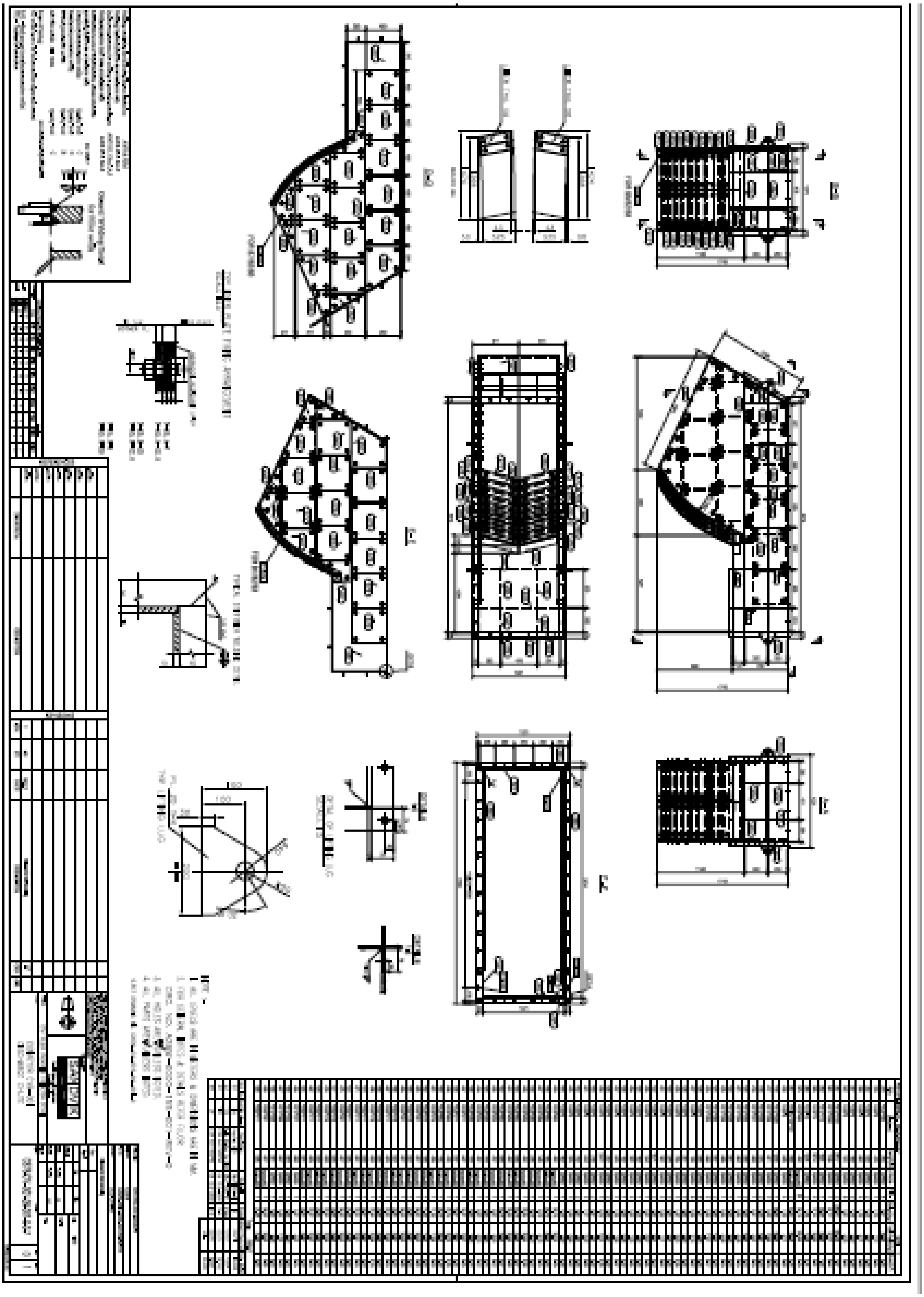
Transfer Chute Technical Drawing



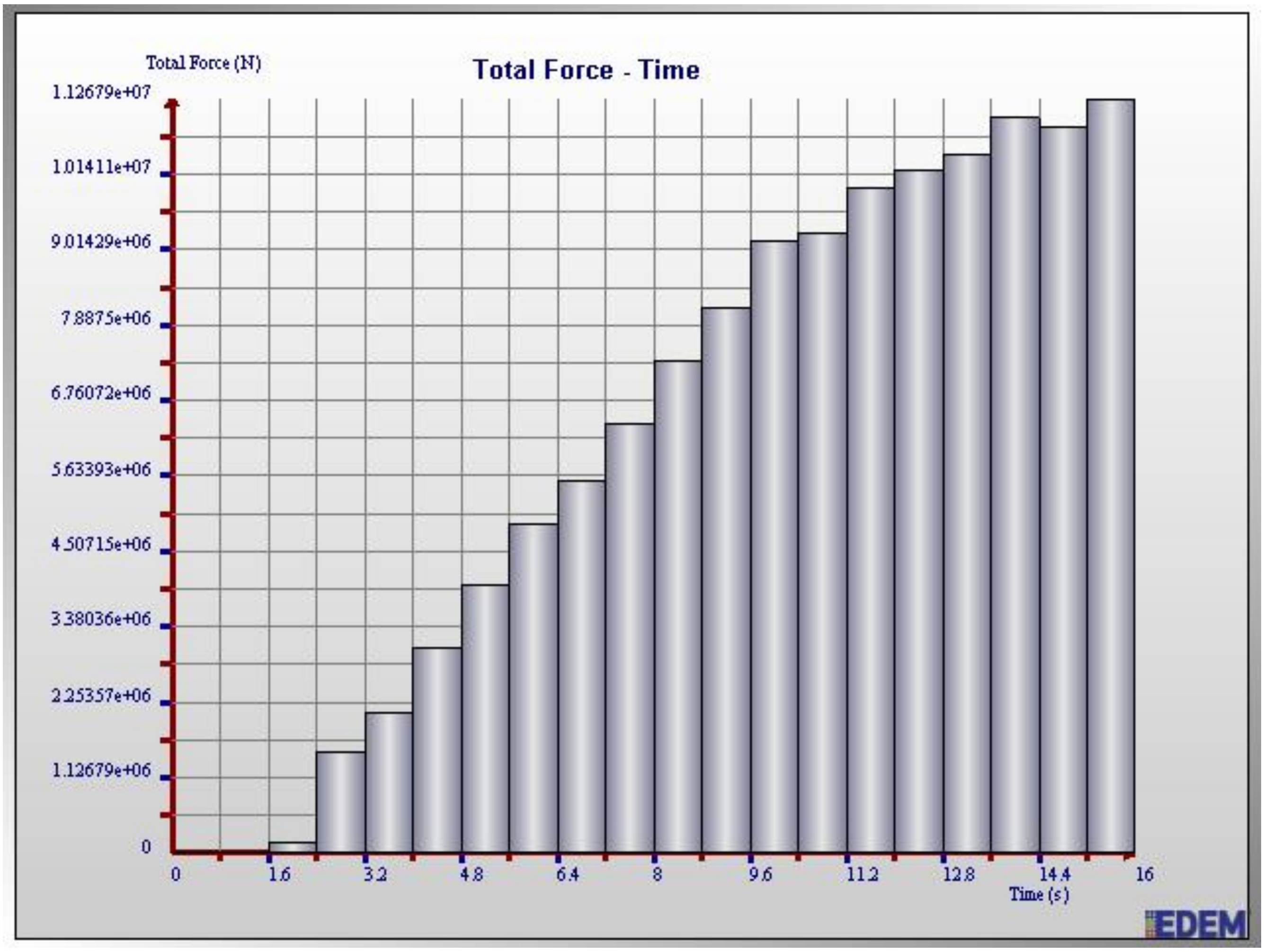




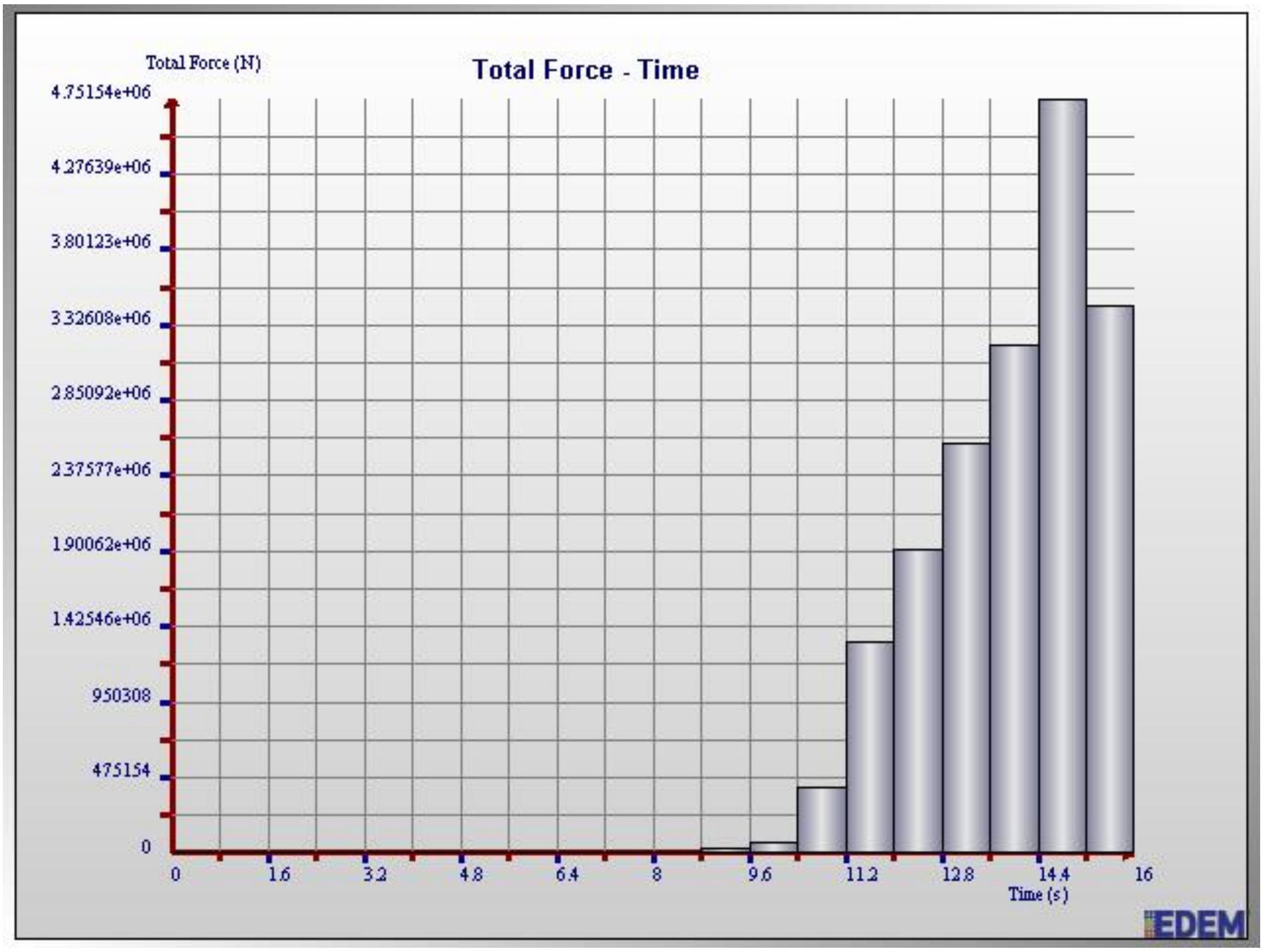




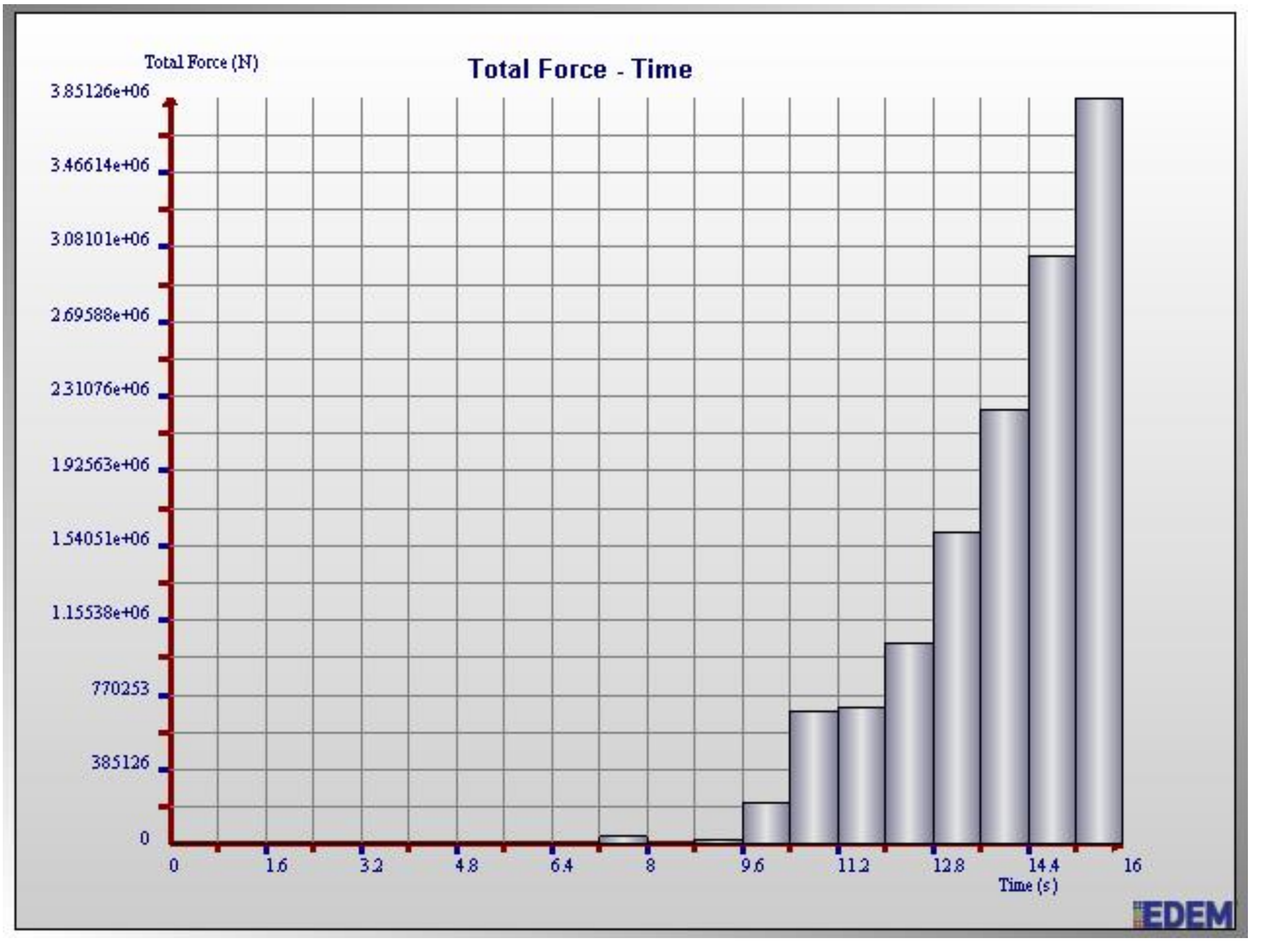
# Appendix B




Histogram: Cumulative Force vs. Time at the Main Body of the Chute




Histogram: Cumulative Force vs. Time at the Valley of the Chute




Histogram: Cumulative Force vs. Time at the Discharge End Box of the Chute

Statutory Declaration

Altangerel, Sukhbat

Last Name, First Name

14405793526624

Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

xxx

independently and without undue external help. I did not use any sources other than those stated. In case that the work is additionally submitted on a data medium, I declare that the written and the electronic form are completely identical. The work was not submitted in the same or similar form to any examination authority.

Ulaanbaatar, Mongolia,
August 19, 2018

Place, Date

Signature