University of Southern Queensland

Faculty of Engineering and Surveying

Millmerran Power Station ROM Coal Blockage Removal System

A dissertation submitted by

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towards the degree of

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ABSTRACT

Millmerran Power Station (MPS) consists of two units with each unit producing 420 MW of electricity. The coal is delivered to the plant by off road type trucks and unloaded into a 500 MT hopper. The ROM (run of mine) coal is processed through a series of crushing stations and coal handling (storage/reclaim) systems, and delivered by overland conveyor to the power plant silos.

MPS, as a coal fired station, is wholly dependent on a consistent and reliable supply of coal to maintain operating efficiency. MPS has been experiencing inefficiencies in their ROM coal supply because of constant blockage issues at the receiving hopper. This blockage is a direct result of large lumps of coal coming from the mine. The blockages interrupt the supply of coal potentially lowering the fuel supply to the power station. Currently, an excavator is hired to clear up the blockage which could be utilised more effectively elsewhere. This introduces an extra cost to the mine in terms of both money and inefficiency. MPS is seeking an engineering design solution to this problem.

The elimination of the blockages through an automatic system without increasing any safety risks is highly desirable as that would result in a cheaper and smoother operation of the mine. A literature review on the current coal handling system of MPS was essential in order to be able to develop a design that is suitable for MPS.

In this investigation, five conceptual designs with the most appropriate design, in terms of meeting the specified criteria, was analysed and detailed. It was found that the simpler and more effective the design, the higher its practicality in terms of reaching the desired objectives. This enabled an overall cost estimate budget to be produced, which would be the major deciding factor on the implementation of the design.

The results of this investigation will aid in gaining an understanding of the overall general solution for the ROM coal blockage problem at MPS. Both design and engineering solutions have been recommended in this dissertation. This will lead eventually to a more automated, safer, efficient and cost effective operating environment.

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CERTIFICATION

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GLOSSARY OF TERMS

The following have been used throughout the text and references:

MOC – Millmerran Operating Company

MPS – Millmerran Power Station

ROM – Run of Mine

NEM - National Electricity Market

PPE – Personal Protective Equipment

MW – Mega Watts

KV – Kilo Volts

MPa – Mega Pascal

MTPH – Mega Tons Per Hour

tph – Turns per hour

PFC – Parallel Flange Channel

RHS – Rolled Hollow Sections

M = Moment force (N/m)

U = Strain Energy (J)

F = Axial load (N)

L = Original beam length (mm)

W = External Work (J)

E = Young's Modulus of Material (MPa)

I = Moment of Inertia (mm^4)

δ - Deflection (mm)

FEA – Finite Element Analysis

Pcr = critical buckling load (N)

E = Modulus of Elasticity (Pa)

J = second moment of area of rod (m^2)

L_e - Free (equivalent) buckling length (m)

P - Maximum safe working load on the piston rod

FOS – Factor of Safety

PLC – Programmable Logic Controller

1. Introduction

Millmerran Operating Company is coal producer and an 880 MW electrical power station (Millmerran Power Station) near the town of Millmerran in southern Queensland. Among the most energy efficient and environmentally advanced coal-fired projects in Australia, the power station became fully operational in early 2003. Millmerran Power Station (MPS) supplies electricity to about 1.1 million homes and sells all of its electricity into the National Electricity Market (NEM), where it is one of the lowest cost generators. Coal for MPS station comes from the adjacent open-cut Commodore mine. Coal is delivered to the power generation facility by means of high capacity mine trucks and is unloaded into an unloading hopper. From the unloading hopper, the run-of-mine (ROM) coal is withdrawn and transported by overland conveyor to silos. The coal passes through an extensive system of coal handling that collects, breaks, transports, feeds, crushes and reduces the coal from an initial ROM size of 1000mm to a 45mm product suitable for use in the power boilers.

At the Commodore mine, a coal hopper with grizzly (grid) is used for the primary collection and crushing of the ROM coal prior to overland conveyor transportation to the adjacent power plant. The grizzly in the hopper is prone to coal blockages which, (1) interrupt the flow of coal to the primary crusher, and (2) affect the effective and efficient running of the operation.

The aims of this project are to research the problem and to develop a safe and cost effective engineering design solution. This chapter commences with an overview of the problem definition and research objectives, includes a very brief introduction to coal and coal mining, and concludes with the dissertation overview.

1.1. Problem Definition

An important aspect for any power station is its reliability and availability. One of the main inputs for a coal fired power station is the coal itself. A disruption in the supply of coal due to a loss of availability may result in reduced capacity to generate or at worst a unit shut down. As its primary fuel source, coal is a vital part of any coal fired power station, as is its coal handling system both at the plant and the mine.

At the Commodore mine, excavated coal is collected by a dump truck and dumped through a 1m x 1m ROM grizzly (grid) into an unloading hopper for primary coal breaking prior to feeding into the overland conveyor transportation link to MPS. Coal builds up on the 1m x 1m ROM grizzly which interrupts the flow of coal into the coal crusher. Currently, an end loader is used to clear this up. This requires the end loader to be generally at the ROM coal site when it could be utilized more effectively elsewhere.

My task is to design a mechanical system to clear the ROM grizzly automatically, or as initiated by coal truck drivers dumping loads of coal through the ROM grizzly.

1.2. Research Objectives

1. Define and describe current Millmerran Power Station (MPS) coal handling system including the mine and the operation of the power station.

2. To undertake a literature review of bulk materials handling, including conveyor design, crusher systems and problems in coal mining industry.

3. Identify significant problems with the current MPS ROM grizzly system.

4. Propose engineering solutions to the identified problems in MPS ROM grizzly system.

5. Conduct a cost benefit analysis of the suggested solutions.

6. Formally report the findings to the project sponsor.

7. Write a dissertation of the project work.

8. Report on any implemented solutions.

1.3. Research Methodology

The primary objective of this project is to identify ways to automatically remove the big lumps of coal that end up on the grizzly, so as to cut the costs of hiring an excavator when it could be utilized more effectively elsewhere, without increasing any safety risks.

I will be using Sketch-Up program to generate initial engineering models of the conceptual designs. ANSYS was used to perform a finite element analysis on the frame. I also used

MATLAB to perform a simple calculation on beam deflections. Pro Engineer was also used to produce a model of the frame so that a finite element analysis could be performed. Four major design criteria will be considered, (1) ease of construction and installation, (2) functionality and effectiveness, (3) ease of operation and maintenance, and (4) costs. Five conceptual designs with the best design, in terms of meeting the criteria, will be analysed and detailed.

In order to achieve the objectives, research relating to the types of coal and methods of coal mining at MPS specifically will be explored, along with a detailed literature review.

1.4. Dissertation Overview

The dissertation begins with an introduction outlining the objectives of the investigation and the methodology undertaken in order to meet those objectives. It includes background information about coal, methods of mining and the uses of coal. Chapter 2 discusses MPS safety management plan and identifies a risk assessment, along with a feasibility study. Chapter 3 provides a background into the different types of power stations, other sources of energy including renewable energy sources, and then into a detailed analysis of fossil fuel plants. Chapter 4 identifies the Millmerran Operating Company, the flow process including explanations of what happens to the coal from the instant it is mined all the way through its delivery to the power station. It also introduces the different types of excavators, crushers and conveyor systems. Chapter 5 discusses the design process, conceptual designs, an analysis of each design followed by a decision matrix. Chapter 6 identifies the components of the main design, and the determination on how much force is required to break coal. Chapter 7 describes the detailed design analysis of the proposed design. Such analyses include beam deflection, finite element analysis, and the design of the hydraulic circuit system. Chapter 8 states the major costs involved in the design and includes a sample cost budget of the engineering design proposed. Finally, a conclusion to the dissertation is presented in Chapter 9.

1.5. Background

1.5.1. Origins of Coal

Coal is a combustible, sedimentary, organic rock formed from ancient vegetation, which has been consolidated between other rock strata and transformed by the combined effects of microbial action, pressure and heat over a considerable time period. Most coal is fossil peat. Peat is an unconsolidated deposit of plant remains from a water-saturated environment such as a bog or mire; structures of the vegetal matter can be seen, and, when dried, peat burns freely. Coal is classified as a non-renewable energy source because it takes millions of years to form. The energy we get from coal today comes from the energy that plants absorbed from the sun millions of years ago. All living plants store energy from the sun through a process known as *photosynthesis.* After the plants die, this energy is released as the plants decay. Under conditions favourable to coal formation, however, the decay process is interrupted, preventing the further release of the stored solar energy (Neuendorf, Mehl & Jackson 2005).

Coal is formed when peat is altered physically and chemically. This process is called *coalification* (refer figure 1). During *coalification*, peat undergoes several changes as a result of bacterial decay, compaction, heat, and time. Peat deposits are quite varied and contain everything from pristine plant parts (roots, bark, spores, etc.) to decayed plants, decay products, and even charcoal if the peat caught fire during accumulation. Peat deposits typically form in a waterlogged environment where plant debris accumulated; peat bogs and peat swamps are examples. In such an environment, the accumulation of plant debris exceeds the rate of bacterial decay of the debris. The bacterial decay rate is reduced because the available oxygen in organic-rich water is completely used up by the decaying process. Anaerobic (without oxygen) decay is much slower than aerobic decay (Lyons & Alpern 1989).

Figure 1 Peat to coal coalification process

For the peat to become coal, it must be buried by sediment. Burial compacts the peat and, consequently, much water is squeezed out during the first stages of burial. Continued burial and the addition of heat and time causes the complex hydrocarbon compounds in the peat to break down and alter in a variety of ways. The gaseous alteration products (including methane) are typically expelled from the deposit, and the deposit becomes more and more carbon-rich as the other elements disperse. The stages of this trend, as illustrated in Figure 2 below, proceed from plant debris through peat, lignite, sub-bituminous coal, bituminous coal, anthracite coal, to graphite (a pure carbon mineral). The peat to coal ratio is variable and dependent on the original type of peat the coal came from and the rank of the coal.
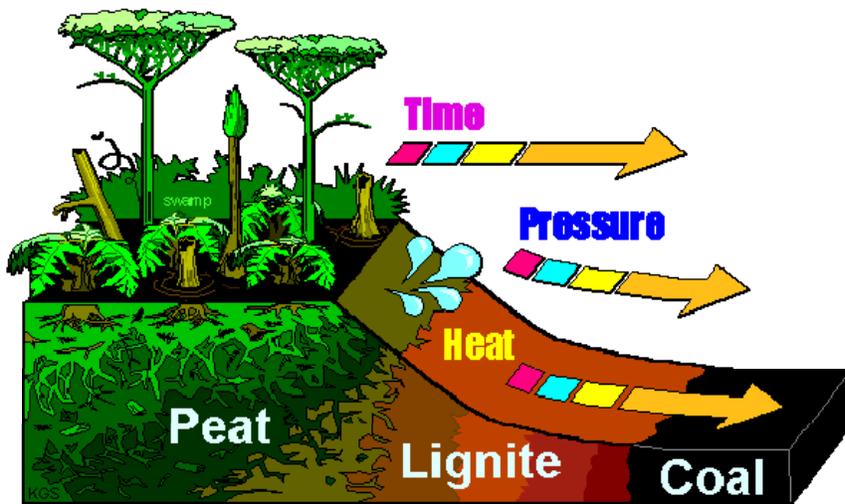
Figure 2 Stages of the Coalification Process

1.5.2. Classification and Rank of Coal

There are two main ways for classifying coal - by *rank* and by *type* (ACA n.d.).

1.5.2.1. Coal Rank

Millmerran ROM Coal Blockage Removal System

The degree of coalification undergone by a coal has an important bearing on its physical and chemical properties, and is referred to as the *rank* of the coal.
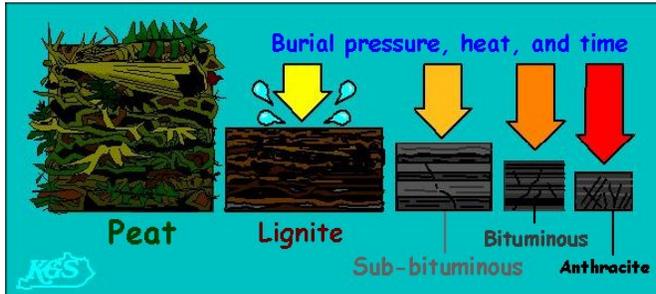
Figure 3 Coals by Rank

The kinds of coal, in increasing order of alteration as illustrated by Figure 3, are lignite (brown coal - immature), sub-bituminous, bituminous, and anthracite (mature). Coal starts off as peat. After a considerable amount of time, heat, and burial pressure, it is metamorphosed from peat to *lignite*. Lignite is considered to be 'immature' coal at this stage of development because it is still somewhat light in colour and it remains soft. As time passes, lignite increases in maturity by becoming darker and harder and is then classified as *sub-bituminous* coal. As this process of burial and alteration continues, more chemical and physical changes occur and the coal is classified as *bituminous*. At this point the coal is dark and hard. *Anthracite* is the last of the classifications, and this terminology is used when the coal has reached ultimate maturation. Anthracite coal is very hard and shiny (Lyons & Alpern 1989).

1.5.2.2 Coal Types

Geologists also classify coal types according to the organic debris, called macerals, from which the coal is formed. The purpose of classifying coal in this way is to determine its best uses. As a finite resource, chemical composition must be matched to the most suitable end use. The mineral or inorganic content of coal is another significant factor affecting end use. Mineral content is assessed by burning coal and measuring the amount of incombustible

material remaining, referred to as the ash content of coal (ACA n.d.; ITAM 2003).
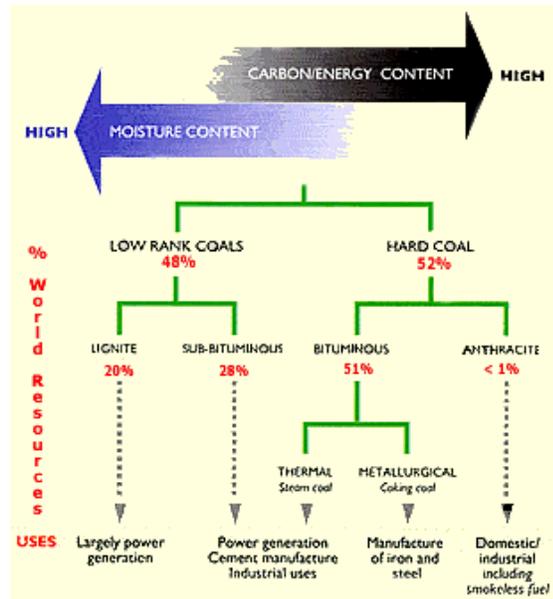
Figure 4 Coals by Type *Source: Coal, Power for Progress - World Coal Institute*

1.5.3. Mining

Mining is the process of obtaining useful minerals from the earth's crust. The process includes excavations in underground mines and surface excavations in open-pit, or open cut (strip) mines. In addition, recent technological developments may soon make the mining of metallic ores from the seafloor economically feasible. Mining normally means an operation that involves the physical removal of rock and earth (Encarta 2007).

A mineral is generally defined as any naturally occurring substance of definite chemical composition and consistent physical properties. An ore is a mineral or combination of minerals from which a useful substance, such as a metal, can be extracted and marketed at a price that will recover the costs of mining and processing and yield a profit. The naturally occurring substances are usually divided into metalliferous ores, such as the ores of gold, iron, copper, lead, zinc, tin, and manganese, and nonmetalliferous minerals, such as coal, quartz, bauxite, trona, borax, asbestos, talc, feldspar, and phosphate rock.

The method chosen for mining will depend on how maximum yield may be obtained under existing conditions at a minimum cost, with the least danger to the mining personnel. The

conditions include the shape, size, continuity, and attitude of the ore body; the mineralogical and physical character of the ore, and the character of the wall rock or overlying material; the relation of the deposit to the surface, to other ore bodies, and to existing shafts on the same property; the skill of available labor; and regional economic conditions. These variables are interdependent and of varying importance, but maximum profit and maximum extraction are closely related, because a method that sacrifices part of the ore body often yields maximum profit. In view of these considerations, open-pit mining tends to be more economical than underground mining, except in regions where climatic conditions are so severe that surface mining is often impossible (Sheldon 2005).

1.5.3.1. Coal Mining

Coal mining is the extraction of coal from the earth for use as fuel. A coal mine and its accompanying structures are collectively known as a *colliery*. The most economical method of coal extraction from coal seams depends on the depth and quality of the seams, and also the geology and environmental factors of the area being mined. Coal mining processes are generally differentiated by whether they operate on the surface or underground.

1.5.3.2. Methods of Mining

Coal is mined by two main methods:

- Underground or 'deep' mining, and;
- Surface or 'open-cut' mining

The choice of method (Figure 4) is largely determined by the geology of the coal deposit, in particular the depth of the seam below the surface. The majority of the world's coal reserves are recoverable by underground mining. Currently, almost two-thirds of hard coal production worldwide comes from underground mines, but in certain important coal producing countries, such as the USA and Australia, his proportion is significantly lower (IEA 1983).
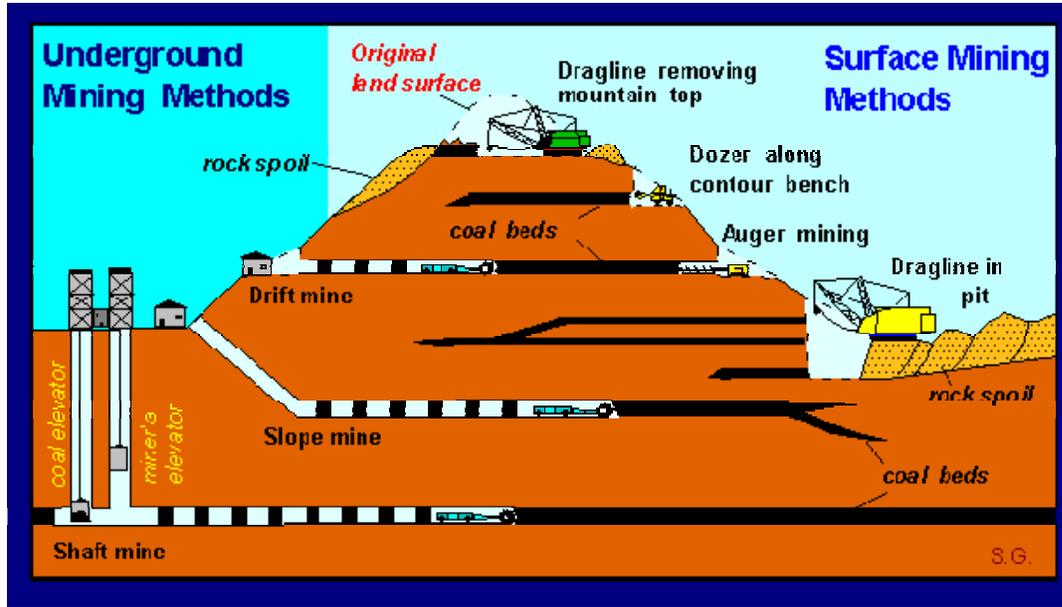
Figure 5 Methods of Mining

1.5.3.2.1. Underground Mining

There are two main methods of extracting coal by underground mining:

- Room-and-pillar mining, and;
- Longwall mining.

Room-and-pillar mining involves cutting a network of 'rooms' or panels into the coal seam and leaving behind 'pillars' of coal to support the roof of the mine (Figure 6). Initially, recoveries are reduced (to 50-60 per cent) because of the coal left in the pillars - however, this coal can sometimes be recovered at a later stage of mine life.
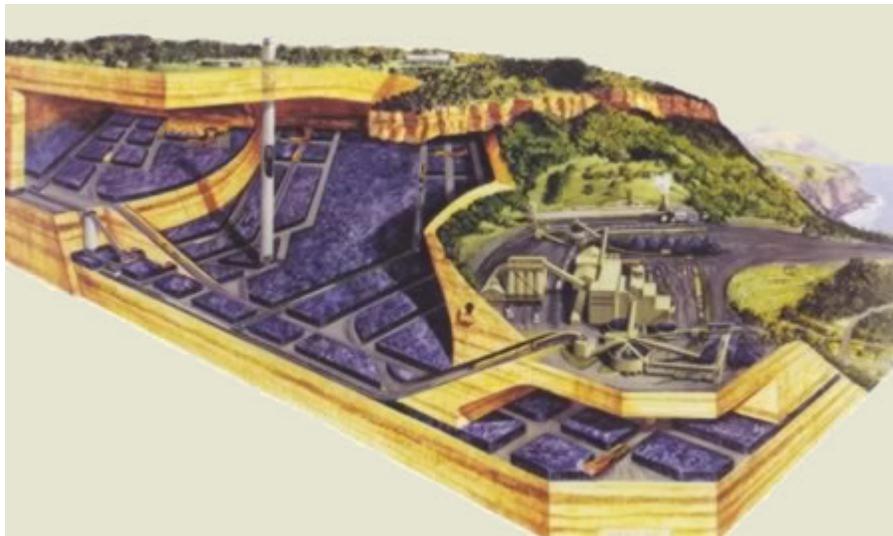
Figure 6 **Cutaway of underground mine, south coast New South Wales, Australia (room and pillar method)**

Longwall mining involves the use of mechanised shearers to cut and remove the coal at the face, which can vary in length from 100-250 m. Self-advancing, hydraulic-powered supports temporarily hold up the roof whilst the coal is extracted. The roof over the area behind the face, from which the coal has been removed, is then allowed to collapse. Over 75 per cent of the coal in the deposit can be extracted using this method.

Figure 7 Longwall Mining

1.5.3.2.2 Open Cut 'Surface' Mining

Surface mining (Figure 8) economic only when the coal seam is relatively close to the surface, recovers a higher proportion of the coal deposit than underground methods.

Figure 8 Open Cut Surface Mining

The equipment used includes: draglines, which remove the overburden (the term given to the strata between the coal seams and the surface); power shovels; large trucks, which transport overburden and coal; bucket wheel excavators; and high capacity conveyors.

Surface mining equipment has increased dramatically in size over recent years. However, in some countries, the high capital cost of importing this equipment can favour the selection of underground mining (ITAM 2003).

1.5.4. Uses of Coal

Coal has a wide range of important uses - the major ones being, electricity generation, steel production and cement manufacture.

2. Project Management

2.1 Project Management

MPS has a comprehensive safety management plan in place that has evolved from extensive consultation with the workforce. Standard Operating Procedures have been developed and are continually reviewed and updated on a scheduled basis as the needs of the project change. Accordingly, as a student engineer, potential employee, contractor or visitor working on an engineering project, it is my responsibility to:

- Appreciate the philosophy behind modern safety legislation;
- Understand my obligations in relation to safety management;
- Accept the possibility that risk of injury or damage is involved with my project; and
- It is my responsibility to identify and minimize this risk

Queensland Government law regulates mining operations (Gunnington 2007) to protect the safety and health of people at mines and quarries through, but not limited to, the *Mining and Quarrying Safety and Health Act* 1999, the *Mining and Quarrying Safety and Health Regulation* 2001 and the *Workplace Health and Safety Act* 1995. Safety and health laws put an obligation or responsibility on all persons at mines to ensure that the level of risk to the safety of persons is managed or kept under control in their workplace, and in any workplace in their area of responsibility. These laws and regulations require that the operational risk of injury and disease must be within acceptable limits and be as low as is reasonably achievable. They also place an obligation on management to have a safe place of work and to maintain safe fixed and mobile plant.

The *Mining and Quarrying Safety and Health Act* 1999 requires an employer to ensure the health safety and welfare of all their employees at a mine. An employer must also ensure that other people at the mine (such as contractors or visitors) are not exposed to any risks arising from the mine or its operation. Under Act the responsibility of an employer extends to ensuring that the premises, the work environment and any work systems are safe and without risk. Plant and substances must be safe when properly used. The employer must also ensure that all information, instruction, training and supervision necessary for health and safety are

provided. Sections of the *Workplace Health and Safety Act* 1995 require an employer to consult with their employees about health and safety. These sections set out various processes for consultation including the establishment of health and safety committees and representatives. Thus, the owner of a mine, as an employer, has a general duty of care under the Act to ensure the health and safety of employees and any other people at the mine. This duty is broad. It covers all risks arising from any hazard found at the mine. This includes hazards not addressed by Act specifically, such as manual handling, hazardous substances, stress and noise. The owner also must consult with employees about the management of health and safety risks.

The mine manager must appoint a range of other managers in a strictly defined hierarchy. The hierarchy is designed to ensure that every area of a mine has a manager on every shift to be responsible for implementing and enforcing the Act and Regulations in their particular area. The Act also sets out specific obligations for different levels of management – mostly to implement prescribed ways of dealing with particular safety matters. For example, a mine manager also appoints people to specified engineering positions - these engineers are given specific safety responsibilities.   Likewise, I am obligated to comply with both the law and company safety management policies to provide risk management for the duration of my project and beyond.

A systematic approach is required to integrate health and safety requirements into my project management activities effectively and to fulfil obligations in relation to health and safety. As I do not have authorization to attend the site, the next section will describe theoretically how this systematic approach would apply to the risk management of my project. This chapter will conclude with a risk assessment and some examples of control measures or ways of reducing risk.

2.2 Risk Management

According to the *Mining and Quarrying Safety and Health Act* 1999, ***risk*** means the risk of injury or illness to a person arising out of a hazard. Risk is ***measured*** in terms of consequences and likelihood of a ***hazard*** which is a thing or a situation with potential to

cause injury or illness to a person. **_Risk management_** is the systematic application of policies, procedures and practices to control risk. It can be achieved by four basic steps:

- Identify the hazards.

- Measure or determine the risks.

- Decide to avoid or remove unacceptable risks

- Develop the controls.

2.2.1 Potential Hazards and Risks

The MPS site involves plant, dump truck, dozer, coal hopper and ROM (raw coal) stockpiles - coal handling activities. My work entails designing and implementing a mechanical engineering solution to grizzly situated at the base of a coal hopper for the primary collection and crushing of the ROM coal. Key hazards, associated with my task and the work environment, would be as follows:

- The Operation of Conveyors and Bulk Materials Handling Systems

- The Safe Operation of Mobile Plant

- The Failure of Structures

- Contact with Moving or Rotating Plant

- Safe Access to Mechanical Plant and Structures

- The use of Fluid Power Systems

- Circumstances Leading to Uncontrolled Fires or Explosions

- Exposure to Hazardous and Toxic Substances

- Exposure to Noise, Vibration and Temperature

- The use of Cutting and Welding Equipment

- Working in Confined Spaces and Restricted Areas

- Working at Heights

The main serious injury or life threatening risks in relation to persons and equipment working on or near my project site would include:

- Person walking on the stockpile either falling into a feeder hole, being buried by a collapsing stockpile face, or being run over by a truck or dozer.

- Person in a light vehicle being hit by a dozer or truck

- Person working in a ROM Hopper – hazardous works

- Electrical shock - contact with live components

- Radiation burns - exposure to welding arc

- Body burns - contact with hot or molten material

- Fire and explosions - welding arc or hot materials and flammable substances

- Eye injury - foreign matter – coal dust

- Noise - Auditory injury or damage

- Sickness - inhalation of fumes

- Heat stress

- Dehydration

Once all the hazards have been identified the most likely outcome, as a result of an incident, should be determined.

2.2.2 Risk Assessment and Control Work Sheet

Each hazard should be evaluated and rated as a level of risk, as per Table 1 below:

1	**HIGH RISK**	*Risk must be eliminated, or at least reduced to a lower grade of risk*
		Potential to cause death or permanent injury
2	**MEDIUM RISK**	*Risk control measures essential*
		Potential to cause one or more lost time injuries
3	**LOW RISK**	*Corrective action required*
		Potential to cause an injury treatable with first aid

Table 1 Level of Risk Classifications

Classification in this way provides an indication of priority in terms of determining risk control measures. The primary goal is to eliminate Level 1 and 2 risks and should be a major focus of the Risk Assessment. The results of the risk assessment must be used to determine what control measures will be taken in order to eliminate the risk, or at least reduce its severity. There is a preferred hierarchy of risk controls which is displayed in Table 2.

HIERARCHY OF CONTROL	
ELIMINATION	Get rid of the hazard out of the workplace.
SUBSTITUTION	Use something less hazardous in place of the identified hazard. For example water based chemicals rather than solvent based ones.
ISOLATION	Put in place barriers to shield or isolate the hazard. For example guards on machines, enclosures for noisy machinery.
ENGINEERING CONTROLS	Put in place a system to counteract the hazard. For example installing an exhaust ventilation system to extract dangerous fumes or dust.
ADMINISTRATIVE CONTROLS	Put in place work routines that reduce the time people are around the hazard.
PERSONAL PROTECTIVE EQUIPMENT	Give people protective equipment and clothing that they have to wear while near the hazard. For example ear plugs or face masks.

SAFE PLACE
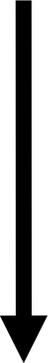
SAFE PERSON

Table 2 Hierarchy of Risk Controls

It is not appropriate to make judgements outside of the scope of my knowledge or area of authorization. Any specific tasks or control measures requiring technical expertise should be further assessed by feedback with the relevant people or the site manager. Risk control measures must be periodically reviewed to make sure they are still effectively containing the risk or to see if better risk control options have become available.

In order for me to demonstrate how I will apply risk management policies and procedures to my project, it is necessary for me to develop a work control sheet. Table 3 illustrates a practical example that includes control measures for selected hazards (identified in section 2.2.1) which I rated as being high or medium risk or both (levels 1 and 2).

In summary, the selection of suitable control measures should take into consideration

- Level of risk
- Hierarchy of controls
- Practicability of implementation.

Activity/Project	• Design, install and maintain mechanical system to clear the ROM grizzly automatically, or as initiated by coal truck drivers dumping loads of coal through the ROM grizzly	**Location:** Millmerran Coal Mine Site (MPS)

Specific Task or Activity	Potential Hazard or Consequences	Risk Rating	Control Measures
Trucks dumping coal on the	Being run over by a truck or dozer	1	Signage and procedure for **no unauthorised entry** into the dump area and a 'call-up' system
Persons working in a ROM hopper	• Coal being dumped or falling on persons working in hopper • Confined space hazards • Persons falling from height	1 & 2	• Truck or other dumping operations to be positively **isolated by barriers**, signage and verbal/written advice to operators. • **Feeder and relevant conveyor system to be isolated & locked out**. • All loose material to be cleaned down from sides and bridge and a safety berm be cleared to prevent ROM stockpile coal from running in. • **Confined space procedure** to be followed if the bottom of the hopper is blocked off. • **Adequate platform and/or edge protection** to be erected within and around top of hopper
Electric Shock	Contact with Live Components	2	• Tools and leads inspected and tagged • Residual current devices installed and tested regularly
Exposure to Noise	Plant and equipment not silenced	2	• Fit noise suppression to noisy plant and equipment • All personnel to wear appropriate PPE

Date: ____/____/____	Supervisor's signature: _____	
Signatures of people involved in the risk assessment:	_____ _____	_____

Table 3 Sample Risk Management Control Work Sheet

2.3. Feasibility Study

A feasibility study is a preliminary study undertaken to determine and document a project's viability. The results of this study are used to make a decision whether to proceed with the project, or table it. It is an analysis of possible alternative solutions to a problem and a recommendation on the best alternative.

Below, I have prepared a **Technical feasibility study**. This involves questions such as whether the technology needed for the system exists, how difficult it will be to build, and whether the firm has enough experience to use that technology.

1. What type of coal is currently being mined?

The type of coal is high ash thermal coal with a Hargreaves index of ~ 40. The coal contains over 36% ash. The size of the material excavated is ~ 1.6m top size, and contains many fines.

2. What is the current daily production?

15000 Tonnes of coal are mined, delivered in 11 hours at 1500 tph.

3. What is the ROM grizzly?

The Run of Mine (ROM) grizzly consists of horizontal and vertical I-beam carbon steel sections forming a big rectangular structure. Its dimensions are 12x7m. The overall structure weighs 8.9 tons.The I-beams have a pointed top, commonly known as a "witch hat", which are used to cut the coal by applying a shearing force as the coal is dumped from a height. Between the points at the top is 1.3m.

4. What is the ROM grizzly used for?

The ROM grizzly is used as a pre-crusher. It acts as a sieve to filter and protect the primary crusher beneath it. Only pieces of coal smaller than $1m^2$ are allowed to go through. Any larger pieces are caught by the grizzly. Larger pieces could end up

chocking the primary crusher, or even damaging it. This could prove very costly if the mining process were interrupted.

5. Why do we need to clear the grizzly?

After every dumping takes place, large pieces of coal become caught in the grizzly. They usually accumulate in the centre region, and end up forming a large pile. The large pieces of coal are a result of the type of mining that takes place. Since the coal seam is relatively near the surface, the strip mining technique is used. This involves an excavator removing long strips of rock. It is the cheapest form of mining. There are no blast crews involved, and that is one main reason why big lumps of coal are mined. As the coal piles up after several trucks have dumped their loads, the next truck comes along. If there is insufficient space on the grizzly for the dumping to take place, the mining process is interrupted. There **NEEDS** to be sufficient space on the grizzly for the dump trucks to do their job, uninterrupted.

6. How often does coal end up on the grizzly?

Depending on what is used to clear the grizzly, the coal can end up on the grizzly after every load, which is roughly 9 times per hour.

7. How long does it take to clear up the grizzly?

Previously, the cleaning used to take roughly 20 minutes per hour using a 992 front-end loader. Currently, a 20T excavator is being used and overall it takes less than one hour per day. It is done about 5 times a day which on average is once every 20 loads.

8. What type of design is MPS looking for?

A mechanical system operated automatically is required to clear the pieces of coal caught by the grizzly, or as initiated by truck drivers dumping coal.

9. What design criteria are being considered?

The main factors that are being considered in the design criteria are, (1) ease of construction and installation, (2) functionality and effectiveness, (2) ease of operation and maintenance and finally, (4) the cost. All of these will be detailed in chapter 5.

10. Any required operator training?

The model has been designed so it operates automatically without any human intervention. This puts a much higher safety and efficiency consideration in the design. For example, a remote sensor is installed that detects the presence of the dumping truck, and initiates the cycle as pre-programmed. If initiating the cycle to start is through the truck drivers for example, there is a chance of a human error factor here, and that is, to forget to do it! The other reason is the high cost of training the operator and the wages involved. The main reason for this design is to lower the costs by not having to employ an operator on site, for instant, to use the excavator or to use the new design.

11. Maintenance?

The model is designed with the least amount of working and moving parts so as to make maintenance costs as small as possible. The less the number of moving parts, the less the wear and tear of the components and hence the maintenance involved. Basic maintenance routines would be involved like lubricating the parts and looking after the correct working of the pumps and motors. When a shutdown is set, the design is safe for any operation to be performed, with little to no risk to any person.

12. Limitations of size and space?

This is definitely one of the greatest considerations that affect the design directly. The receiving hopper is suspended 30m in the air, and access to the grizzly is from one side only, hence the reason why the trucks need to reverse into the grizzly, and the use of rear dump trucks. The puts a great limitation to the design since for convenience, one would want all the components to be inside the shed. In other words, there were several design

ideas that involved installing parts on the back of the shed, but that meant after careful consideration, that a whole new platform would need to be installed on the back of the shed for initial installation, and later on, maintenance. This puts a whole new unnecessary cost on MPS. Therefore the design had to fit inside the shed with all its components inside for easy installation and maintenance in the running cycle of the design.

3. Power Stations Review and Operation

A power station is a facility for the generation of electric power and is involved in the conversion of other forms of energy, like chemical energy, gravitational potential energy or heat energy into electrical energy.

At the center of nearly all power stations is a generator - a rotating machine that converts mechanical energy into electrical energy by creating relative motion between a magnetic field and a conductor. The energy source harnessed to turn the generator varies widely. It depends chiefly on what fuels are easily available and the types of technology that the power company has access to (Elliott, Chen & Swanekamp 1997).

3.1. Thermal Power Stations

In thermal power stations, mechanical power is produced by a heat engine, which transforms thermal energy, often from combustion of a fuel, into rotational energy. Most thermal power stations produce steam, and these are sometimes called steam power stations. Not all thermal energy can be transformed to mechanical power, according to the second law of thermodynamics. Therefore, there is always heat lost to the environment.

3.1.1. Classification

Thermal power plants are classified by the type of fuel and the type of prime mover installed.

By fuel

- Nuclear power plants use a nuclear reactor's heat to operate a steam turbine generator.
- Fossil fuel powered plants may also use a steam turbine generator or in the case of Natural gas fired plants may use a combustion turbine.
- Geothermal power plants use steam extracted from hot underground rocks.

- Renewable energy plants may be fuelled by waste from sugar cane, municipal solid waste, landfill methane, or other forms of biomass.
- In integrated steel mills, blast furnace exhaust gas is a low-cost, although low-energy-density, fuel.
- Waste heat from industrial processes is occasionally concentrated enough to use for power generation, usually in a steam boiler and turbine.

By prime mover

- Steam turbine plants use the pressure generated by expanding steam to turn the blades of a turbine.
- Gas turbine plants use the heat from gases to directly operate the turbine. Natural-gas fuelled turbine plants can start rapidly and so are used to supply "peak" energy during periods of high demand, though at higher cost than base-loaded plants.
- Combined cycle plants have both a gas turbine fired by natural gas, and a steam boiler and steam turbine which use the exhaust gas from the gas turbine to produce electricity. This greatly increases the overall efficiency of the plant, and most new base load power plants are combined cycle plants fired by natural gas.
- Internal combustion reciprocating engines are used to provide power for isolated communities and are frequently used for small cogeneration plants. Hospitals, office buildings, industrial plants, and other critical facilities also use them to provide backup power in case of a power outage. These are usually fuelled by diesel oil, heavy oil, natural gas and landfill gas.
- Microturbines, stirling engines and internal combustion reciprocating engines are low cost solutions for using opportunity fuels, such as landfill gas, digester gas from water treatment plants and waste gas from oil production.

3.3. Fossil Fuel Power Plant

In a fossil fuel power plant the chemical energy stored in fossil fuels such as coal, fuel oil, natural gas or oil shale is converted successively into thermal energy, mechanical energy and, finally, electrical energy for continuous use and distribution across a wide

geographic area. Almost all large fossil fuel power plants are steam-electric power plants, except for gas turbines and utility-sized reciprocating engines that may run on natural gas or diesel.

The burning of fossil fuel is summarized in the following chemical reaction:

$$\text{Fuel} + \text{Oxygen} \rightarrow \text{Heat} + \text{Carbon dioxide} + \text{Water} \quad \text{(eqn 1)}$$

All fossil fuels generate carbon dioxide, when combusted. Chemical side reactions also take place, generating, among others, sulfur dioxide (predominantly in coal) and oxides of nitrogen (Sami, Annamalai & Wooldridge 2001).

3.3.1. Fuel transport and delivery

Coal is delivered by mass transport systems, truck, rail, barge or collier. Australia's current generation of trains each can carry between 2100 and 8600 net tonnes of coal (Australian_Government 2006). Road transport is used for short distance haulage, and is an effective method when the mine site is located far away from the rail head. Conveyor systems are used to transport the coal from mine site directly to the rail head or to coal fired electricity plants. A large plant under full load requires at least one coal delivery every day. Plants may get as many as three to five trains a day, especially in "peak season", during the summer months when power consumption is high. Modern unloaders use rotary dump devices, which eliminate problems with coal freezing in bottom dump cars. The unloader includes a train positioner arm that pulls the entire train to position each car over a coal hopper. The dumper clamps an individual car against a platform that swivels the car upside down to dump the coal. Swiveling couplers enable the entire operation to occur while the cars are still coupled together. Unloading a unit train takes about three hours.

Shorter trains may use railcars with an "air-dump", which relies on air pressure from the engine plus a "hot shoe" on each car. This "hot shoe" when it comes into contact with a "hot rail" at the unloading trestle, shoots an electric charge through the air dump

apparatus and causes the doors on the bottom of the car to open, dumping the coal through the opening in the trestle. Unloading one of these trains takes anywhere from an hour to an hour and a half. Older unloaders may still use manually operated bottom-dump rail cars and a "shaker" attached to dump the coal. Generating stations adjacent to a mine may receive coal by conveyor belt or massive diesel-electric-drive trucks.

A collier (cargo ship carrying coal) may hold 40,000 tons of coal and takes several days to unload. Some colliers carry their own conveying equipment to unload their own bunkers; others depend on equipment at the plant. Colliers are large, seaworthy, self-powered ships. For transporting coal in calmer waters, such as rivers and lakes, flat-bottomed vessels called barges are often used. Barges are usually unpowered and must be moved by tugboats or towboats.

3.3.2. Fuel Processing

Coal is prepared for use by crushing the rough coal to pieces less than 2 inches (50 mm) in size. The coal is transported from the storage yard to in-plant storage silos by rubberized conveyer belts at rates up to 4,000 tons per hour. A 400 ton silo may feed each coal pulveriser (coal mill) at a rate of up to 60 tons per hour. Coal fed into the top of the pulveriser and ground to a powder, the consistency of face powder, is blown, with air, into the furnace.

3.3.3. Feedwater Heating

The feedwater used in the steam boiler is a means of transferring heat energy from the burning fuel to the mechanical energy of the spinning steam turbine. The total feedwater consists of recirculated condensed steam, referred to as *condensate*, from the steam turbines plus purified *makeup water*. Because the metallic materials it contacts are subject to corrosion at high temperatures and pressures, the makeup water is highly purified before use. A system of water softeners and ion exchange demineralisers produces water so pure that it coincidentally becomes an electrical insulator, with conductivity in the range of 0.3–1.0 microsiemens per centimeter.

The feedwater cycle begins with condensate water being pumped out of the condenser after traveling through the steam turbines. The water flows through a series of six or seven intermediate feedwater heaters, heated up at each point with steam extracted from an appropriate duct on the turbines and gaining temperature at each stage. Typically, the condensate plus the makeup water then flows though a deaerator that removes dissolved air from the water, further purifying and reducing its corrosivity. The water may be dosed following this point with hydrazine, a chemical that removes the remaining oxygen in the water to below 5 parts per billion (ppb). It is also dosed with pH control agents such as ammonia or morpholine to keep the residual acidity low and thus non-corrosive.

3.3.4. Boiler Operation

The boiler is a rectangular furnace about 50 ft (15 m) on a side and 130 ft (40 m) tall. Its walls are made of a web of high pressure steel tubes about 2.3 inches (60 mm) in diameter.

Pulverized coal is air-blown into the furnace from fuel nozzles at the four corners and it rapidly burns, forming a large fireball at the center. This heats the water that circulates through the boiler tubes. The water circulation rate in the boiler is three to four times the throughput and is typically driven by pumps. As the water in the boiler circulates it absorbs heat and changes into steam at 370 °C and 22.1 MPa. It is separated from the water inside a drum at the top of the furnace. The saturated steam is introduced into superheat pendant tubes that hang in the hottest part of the combustion gases as they exit the furnace. Here the steam is superheated to 540 °C to prepare it for the turbine.

3.3.5. Steam Turbine Generator

The turbine generator consists of a series of steam turbines interconnected to each other and a generator on a common shaft. There is a high pressure turbine at one end, followed by an intermediate pressure turbine, two low pressure turbines, and the generator. As steam moves through the system and loses pressure and temperature energy it expands in volume, requiring increasing diameter and longer blades at each succeeding stage to extract the remaining energy. The entire rotating mass may be over 200 tons and 100 ft

(30 m) long. It is so heavy that it must be kept turning slowly even when shut down (at 3 rpm) so that the shaft will not sag even slightly and become unbalanced. This is so important that it is one of only four functions of blackout emergency power batteries on site. They are emergency lighting, communication, station alarms and turbogenerator turning gear. Superheated steam from the boiler is delivered through 350–400 mm diameter piping to the high pressure turbine where it falls in pressure to 4 MPa and to 315 °C through the stage. It exits via 600–650 mm diameter cold reheat lines and passes back into the boiler where the steam is reheated in special reheat pendant tubes back to 540 °C. The hot reheat steam is conducted to the intermediate pressure turbine where it falls in both temperature and pressure and exits directly to the long-bladed low pressure turbines and finally exits to the condenser.

The generator, 9 m long 3.7 m diameter, contains a stationary stator and a spinning rotor, each containing miles of heavy copper conductor—no permanent magnets here. In operation it generates up to 21,000 amps at 24,000 volts AC as it spins at either 3,000 or 3,600 RPM, synchronized to the power grid. The rotor spins in a sealed chamber cooled with hydrogen gas, selected because it has the highest known heat transfer coefficient of any gas and for its low viscosity which reduces windage losses. This system requires special handling during startup, with air in the chamber first displaced by carbon dioxide before filling with hydrogen. This ensures that the highly flammable hydrogen does not mix with oxygen in the air.

3.3.6. Steam Condensing

The lower the pressure of the exhaust steam leaving the low pressure turbine the more efficient is the train of turbine stages. The exhaust steam from the low pressure turbine enters condenser-tube bundles that have cooling water circulating through them. Typically the cooling water causes the steam to condense at a temperature of about 32–38 °C (90–100 °F) and that creates an absolute pressure in the condenser of about 5–7 kPa (1.5–2.0 in Hg), a vacuum of about 95 kPa (28 mmHg) relative to atmospheric pressure. The condenser, in effect, creates the low pressure required to drag steam through and increase the efficiency of the turbines. The limiting factor is the temperature of the

cooling water and that, in turn, is limited by the prevailing average climatic conditions at the power plant's location.

From the bottom of the condenser, powerful pumps recycle the condensed steam (water) back to the feedwater heaters for reuse. The heat absorbed by the circulating cooling water in the condenser tubes must also be removed to maintain the ability of the water to cool as it circulates.

This is done by pumping the warm water from the condenser through either natural draft, forced draft or induced draft cooling towers that reduce the temperature of the water, by 11–17°C, by evaporation - expelling waste heat to the atmosphere. The circulation flow-rate of the cooling water in a 500 MW unit is about 14.2 m^3/s at full load.

The condenser tubes are made of brass or stainless steel to resist corrosion from either side. Nevertheless they may become internally fouled during operation by bacteria or algae in the cooling water or by mineral scaling, all of which inhibit heat transfer and reduce thermodynamic efficiency. Many plants include an automatic cleaning system that circulates sponge rubber balls through the tubes to scrub them clean without the need to take the system off-line.

Another form of condensing system is the air-cooled condenser. While these systems are similar in operation to mechanical cooling towers, they typically are more environmentally acceptable forms of condensing steam. The process is similar to that of a radiator and fan. Exhaust heat from the low pressure section of a steam turbine runs through the condensing tubes, the tubes are usually finned and ambient air is pushed through the fins with the help of a large fan. The steam condenses to water to be reused in the water-steam cycle.

Millmerran ROM Coal Blockage Removal System
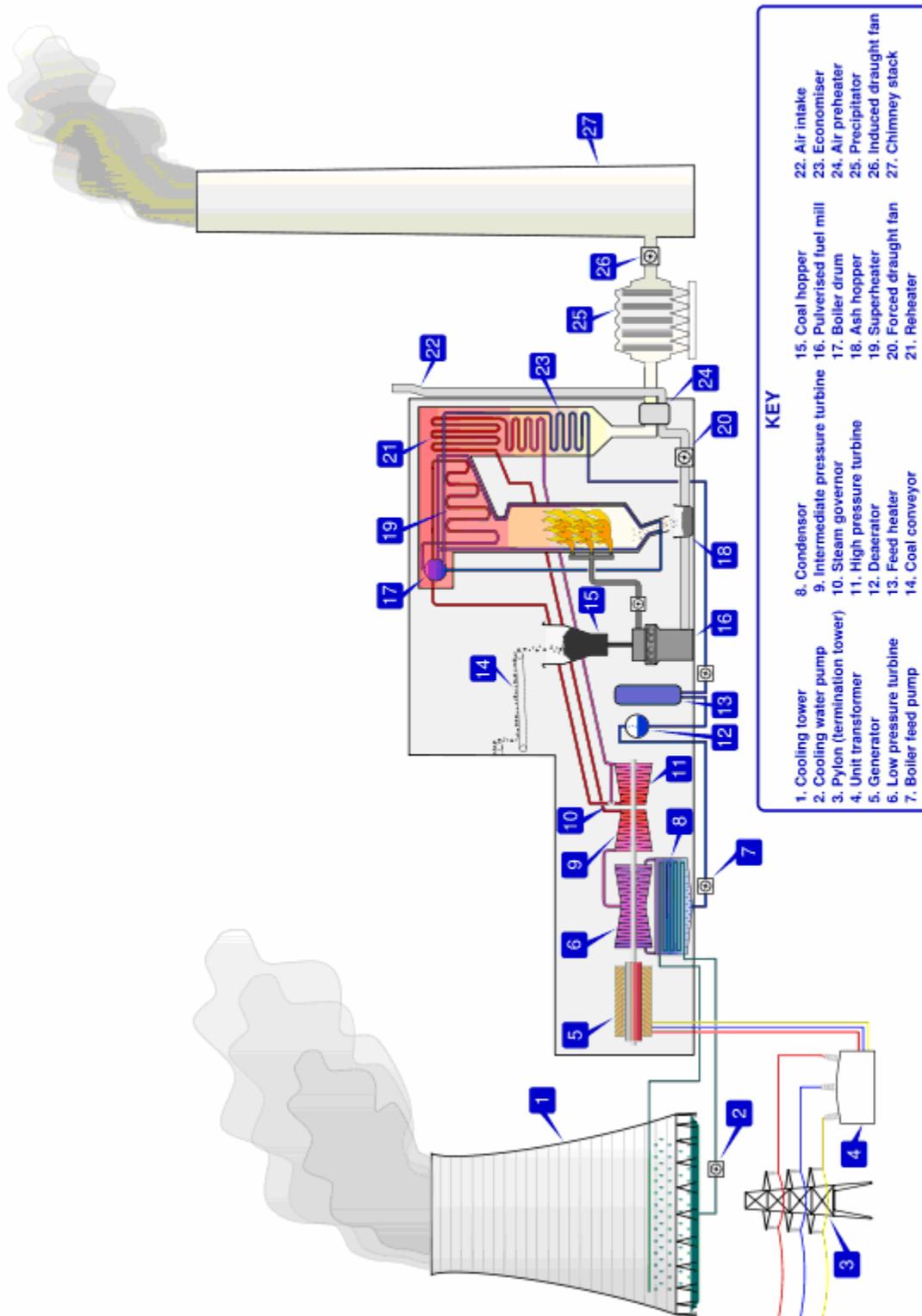
Key

1. Cooling tower	10. Steam governor	19. Superheater
2. Cooling water pump	11. High pressure turbine	20. Forced draught fan
3. Three-phase transmission line	12. Deaerator	21. Reheater
4. Unit transformer	13. Feed heater	22. Air intake
5. Generator	14. Coal conveyor	23. Economiser
6. Low pressure turbine	15. Coal hopper	24. Air preheater
7. Boiler feed pump	16. Pulverised fuel mill	25. Precipitator
8. Condensor	17. Boiler drum	26. Induced draught fan
9. Intermediate pressure turbine	18. Ash hopper	27. Chimney stack

Description: A coal-fired thermal power station

Coal is conveyed (14) from an external stack and ground to a very fine powder by large metal spheres in the pulverised fuel mill (16). There it is mixed with preheated air (24) driven by the forced draught fan (20). The hot air-fuel mixture is forced at high pressure into the boiler where it rapidly ignites. Water of a high purity flows vertically up the tube-lined walls of the boiler, where it turns into steam, and is passed to the boiler drum (17), where steam is separated from any remaining water. The steam passes through a manifold in the roof of the drum into the pendant superheater (19) where its temperature and pressure increase rapidly to around 200 bar and 570°C, sufficient to make the tube walls glow a dull red. The steam is piped to the high pressure turbine (11), the first of a three-stage turbine process. A steam governor valve (10) allows for both manual control of the turbine and automatic set-point following. The steam is exhausted from the high pressure turbine, and reduced in both pressure and temperature, is returned to the boiler reheater (21). The reheated steam is then passed to the intermediate pressure turbine (9), and from there passed directly to the low pressure set (6). The steam, now little above its boiling point, is brought into thermal contact with cold water in the condenser (8), where it condenses rapidly back into water, creating a near vacuum inside the condenser chest. The condensed water is then passed by a feed pump (7) through a deaerator (12), and pre-

warmed, first in a feed heater (13) powered by steam drawn from the high pressure set, and then in the economiser (23), before being returned to the boiler drum. The water from the condenser is sprayed inside a cooling tower (1), creating a highly visible plume, before being pumped back to the cooling water cycle.

The three turbine sets are coupled on the same shaft as the electrical generator (5) which generates an intermediate level voltage (typically 20-25 kV). This is stepped up by the unit transformer (4) to a voltage more suitable for transmission (typically 250-500 kV) and is sent out onto the transmission system (3). Exhaust gas from the boiler is drawn by the induced draft fan (26) through an electrostatic precipitator (25) and is then vented through the chimney stack (27).

3.3.7. Stack Gas path and Cleanup

As the combustion flue gas exits the boiler it is routed through a rotating flat basket of metal mesh which picks up heat and returns it to incoming fresh air as the basket rotates, This is called the air pre-heater. The gas exiting the boiler is laden with fly ash, which are tiny spherical ash particles. The flue gas contains nitrogen along with combustion products carbon dioxide, sulfur dioxide, and nitrogen oxides. The fly ash is removed by fabric bag filters or electrostatic precipitators. Once removed, the fly ash byproduct can sometimes be used in manufacture of concrete. This cleaning up of flue gases, however, only occurs in plants that are fitted with the appropriate technology.

Where required by law, the sulfur and nitrogen oxide pollutants are removed by stack gas scrubbers which use a pulverized limestone or other alkaline wet slurry to remove those pollutants from the exit stack gas. The gas traveling up the flue gas stack may by this time only have a temperature of about 50 °C. A typical flue gas stack may be 150–180 m tall to disperse the remaining flue gas components in the atmosphere.

3.4. Supercritical Steam Plants

Above the critical point for water of 374 °C and 22.1 MPa, there is no phase transition from water to steam, but only a gradual decrease in density. Boiling does not occur and it is not possible to remove impurities via steam separation. In this case a new type of design is required for plants wishing to take advantage of increased thermodynamic efficiency available at the higher temperatures. These plants, also called once-through plants because boiler water does not circulate multiple times, require additional water purification steps to ensure that any impurities picked up during the cycle will be removed. This takes the form of high pressure ion exchange units called condensate polishers between the steam condenser and the feedwater heaters. Sub-critical fossil fuel power plants can achieve 36–38% efficiency. Supercritical designs have efficiencies in the low to mid 40% range, with new "ultra critical" designs using pressures of 30 MPa and dual stage reheat reaching about 48% efficiency.

3.5. Environmental Impacts

Fossil fuel power contributes to acid rain, global warming, and air pollution. Acid rain is caused by the emission of nitrogen oxides and sulphur dioxide into the air. These may be only mildly acidic. Yet when it reacts with the atmosphere; it creates acidic compounds such as (nitric acid) and sulphuric acid that fall as rain. Hence, the term acid rain. In Europe, stricter emission laws have reduced the environmental hazards associated with this problem.

Another danger related to coal combustion is the emission of fly ash, tiny solid particles that are dangerous for public health. (Natural gas plants emit virtually no fly ash) These can be filtered out of the stack gas, although this does not happen everywhere. The most modern plants that burn coal use a different process, in which synthesis gas is made out of a reaction between coal and water. This is purified of most pollutants and then used initially to power gas turbines, and then the residual heat is used for a steam turbine. The pollution levels of such plants are drastically lower than those of "classical" coal power plants. However, all coal burning power plants emit carbon dioxide. Research has shown

that increased concentration of carbon dioxide in the atmosphere is positively correlated with a rise in mean global temperature (Houghton et al. 2001).

4. Millmerran Power Station Overview

Millmerran Power is a two unit generating station located near the town of Millmerran in southern Queensland and is among the most energy efficient and environmentally advanced coal-fired projects in Australia.

The plant consists of two units with each unit producing over 420 MW of electricity. At maximum continuous rating the combined boiler firing rate will be 434 MTPH (217 MTPH per unit) of coal from the adjacent mine. Coal is delivered to the facility by means of high capacity mine trucks and unloaded into the unloading hopper. From the unloading hopper, the run-of-mine (ROM) coal is withdrawn by a feeder-breaker, which reduces the coal from a maximum 1000 mm to a nominal 200 mm product at a rate of 1,500 tph.

The coal then discharges from the feeder breaker into a chute which feeds a secondary crusher which reduces the coal to nominal 100 mm product. The coal then is discharged onto the unloading conveyor, which conveys and discharges the coal onto the overland conveyor.

The 1500 MTPH overland conveyor transports coal to transfer tower number 2 a distance of approximately one mile. A diverting gate provided at the head end of the overland conveyor allows the option of either discharging coal onto the stacking conveyor (for stacking out coal onto the coal piles) or discharging onto the crusher feed conveyor (for sending coal directly to the power block). Coal that is diverted to the stacking conveyor is discharged onto the active pile by a travelling linear stacker rated at 1500 MTPH. Coal from the active pile is reclaimed using a full portal scraper reclaimer, dual rated at 750MTPH/1500 MTPH.

The reclaim conveyor transports coal at up to 1500 MTPH back to transfer tower no.2 for discharging onto the crusher feed conveyor. The 1500 MTPH crusher feed conveyor transports coal to the crusher tower where the coal passes under a magnetic separator before being discharged into the 100 metric ton surge bin. Each of the two outlets of the surge bin are provided with isolation gates. Coal is discharged into two 50% capacity

crushers rated at 750 MTPH via the crusher feeders. Each crusher reduces the coal feed size from 100 mm to a maximum of 45 mm. From the crusher tower, coal is transferred via two power block feed conveyors; each rated at 750 MTPH, to the Unit 1 silo bay. At the power block, a diverting gate is used to discharge coal to either the unit 1 silo feed conveyor or to the transfer conveyor, which transports coal to the Unit 2 silo feed conveyor at 1500 MTPH. Each silo feed conveyor includes a travelling tripper, which is used to discharge coal to the silos. The total capacity of the silos for each unit is 2750 metric tons to accommodate approximately 10 hours of boiler operation. An at-grade emergency reclaim hopper with vibrating grizzly and a 750 MTPH emergency reclaim conveyor, equipped with a vibratory feeder, is used to reclaim coal from the storage piles by using mobile equipment.

Figure 9 Millmerran Power Station

4.1. How does Coal get to the grizzly?

4.1.1. Types of Haul Units

There are many types and sizes of haul units, some of which are of use for special work while others can be used for almost anything. The types available for use in the mining industry are usually dumpers and dump trucks.

4.1.1.1 Dumpers

These are very useful machines, usually powered by diesel engines, with a wide range of sizes of forward tipping skips or bowls. They are designed with positive steering, are very manoeuvrable and travel well on the rough and muddy roads. Dumpers employed for moving earth with an excavator have a heaped capacity between 4 and 8m cubed. Various specially shaped bowls can be fitted to carry coal.

4.1.1.2. Dump Trucks

These are specially designed for hauling excavated materials on or off the highway. They are fitted with high-capacity metal bowls that are designed for easy filling and quick, clean tipping. Several types of bowl are available for various materials. The bowls are mounted on robust steel chassis, usually have four wheel drives and discharge their loads by tipping to the rear. The capacity of these trucks usually varies from 3 to 29 m cubes.

4.1.2 How it takes place on-site

Strip mining is the practice of mining a seam of mineral by first removing a long strip of overlying soil and rock (the overburden). It is most commonly used to mine <u>coal</u> or tar sand. Strip mining is only practical when the ore body to be excavated is relatively near the surface. Coal is extracted by a front end loader, which fills the 773 Cat model rear dump truck, as shown in figure 10 below:

Figure 10 Coal being filled into a rear dump truck

The truck carries 54 ton of coal at a loaded top speed of 68km/hr, and then reverses into the grizzly and dumps the coal as shown in Figure 11.

Figure 11 Truck dumping coal into grizzly

4.2. What is the grizzly?

As discussed earlier, the grizzly consists of horizontal and vertical I-beam sections intersecting forming squares that measure 1mx1m. They have a pointy top commonly known as a "witch hat" which is used to shear the coal as it gets dumped by the truck. The area between the points at the top is 1.3m.

You can see in the figure below, how the effect of the excavator results in damage to the grizzly. This is demonstrated by the major bends and flattening of the I beam sections causing major inefficiencies as the grizzly loses its mechanical properties. Over exposure of the grizzly to the excavator would slowly result in more damage. Therefore, a mechanical automatic system needs to be installed. The I beams catch coal as shown in Figure 12:

Figure 12 ROM Grizzly

4.3. What happens to the coal?
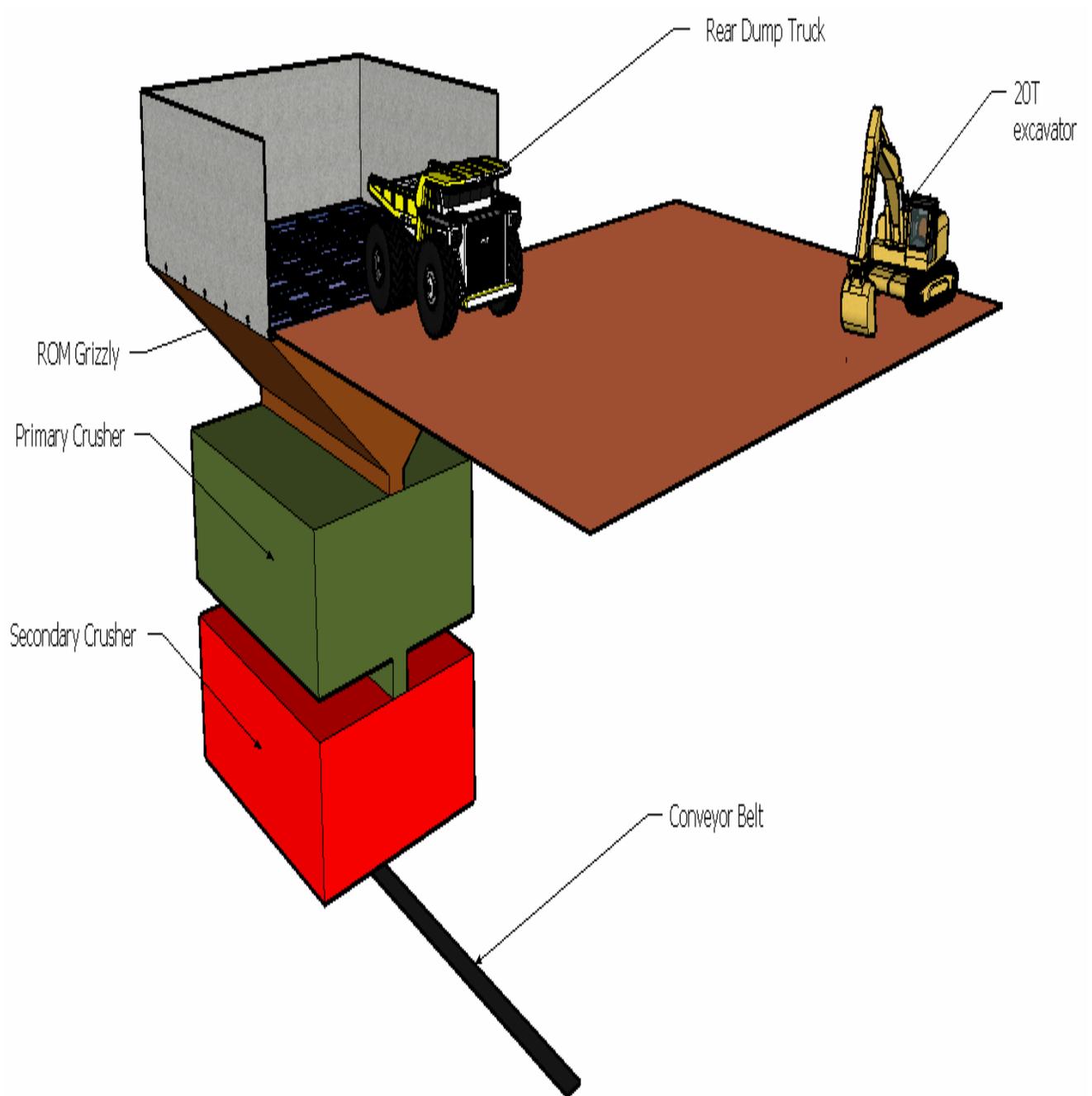
Figure 13 ROM Coal Handling Plant

4.3.1. Excavators

Excavators form the backbone of most mining sites, and they are used to dig and load earth and similar materials. Due to the nature of their work, they are usually mounted on crawler tracks. Wheeled types are available as well as others mounted on the back of road lorries. The size of any excavator is governed by the power rating of the engine which, in turn, determines the bucket or shovel capacity.

4.3.1.1. Back actor or drag shovel

A universal excavator equipped as a back-acting machine is another very useful combination. A short jib, used with the face shovel, is removed and fitted at the end of the main jib, this time with the bucket facing the machine. This is extremely useful for excavating in trenches and basements, and the machine is able to excavate well below its own level. To increase the reach and also to give more variable control to the bucket, hydraulic rams have been fitted to the short jibs of some excavators with them working quite well. This type of shovel can be used for loading work.

In our situation, the excavator serves a whole different purpose. It is generally parked off the road to make a clear road for the rear dumper. However, only once every 21 loads, the 20T excavator is used to smash the big lumps of coal piled up round the centre region of the grizzly. It uses its shovel to also push some of the lumps round the outside area of the grizzly leaving enough empty space round the centre of the grizzly for the next load.

4.3.2. Crushers

A crusher is a machine designed to reduce large solid chunks of raw material into smaller chunks which may become more usable. Crushers are commonly classified by the degree to which they fragment the starting material, with coarse crushers not reducing it by much, intermediate crushers fragmenting it much more significantly, and grinders reducing it to a fine powder.

4.3.2.1. Rock Crushers

A rock crusher is a machine designed to take large rocks and reduce them to smaller rocks, gravel, or rock dust. Rock crushers produce aggregates and ready-to-process mining ores, as well as rock fill material for landscaping and erosion control. Crushing is the first step in converting shot rock into usable products, by taking large rocks and reducing them to smaller pieces. Crushing is sometimes continued until only fines remain. At some operations, all the crushing is accomplished in one step, by a primary crusher. At other operations, crushing is done in two or three steps, with a primary crusher that is followed by a secondary crusher, and sometimes a tertiary crusher or even a quaternary crusher.

Raw material, of various sizes, is brought to the primary crusher by rear-dump haul units, or carried by a wheel front-end loader. Primary crushing reduces this run-of-mine rock to a more manageable size.

4.3.2.2. Types of Crushers

4.3.2.2.1. Jaw

The jaw crusher squeezes rock between two surfaces, one of which opens and closes like a jaw. Rock enters the jaw crusher from the top. Pieces of rock larger than the opening at the bottom of the jaw lodge between the two metal plates of the jaw. The opening and closing action of the movable jaw against the fixed jaw continues to reduce the size of lodged pieces of rock. This occurs until the pieces are small enough to fall through the opening at the bottom of the jaw. It has a very powerful motion.

4.3.2.2.2. Gyratory

A gyratory crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle (which is covered by a wear resistant mantle) and the enclosing concave hopper. As run-of-mine rock enters the top of the gyratory crusher, it becomes wedged and squeezed between the mantle and concaves. Large pieces of ore are broken once and then

fall to a lower position (because they are now smaller) where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

4.3.2.2.3. Impact

There are two types of impact crushers; the Horizontal Shaft Impactor (HSI) and the Vertical Shaft Impactor (VSI). The HSI crushers break rock by impacting the rock with hammers that swing on a rotating shaft. The practical use of HSI crushers is limited to soft materials and non abrasive materials, such as limestone, phosphate, gypsum, weathered shales. HSI crushers achieve the highest degree of reduction. The VSI crushers can also break rock by impacting the material with rotating hammers. Traditionally this is referred to as a "Shoe and Anvil VSI" and has similar limitations to the HSI crusher. The Barmac VSI crusher uses a different method involving a rotor with wear resistant tips and a crushing chamber designed to retain a protective layer crushed rock. Using this method, materials with much higher abrasiveness can be crushed.

4.3.2.2.4. Cone

A cone crusher is similar in operation to a gyratory crusher, with less steepness in the crushing chamber and more of a parallel zone between crushing zones. A cone crusher breaks rock by squeezing the rock between an eccentrically gyrating spindle. The spindle is covered by a wear resistant mantle and the enclosing concave hopper is covered by a manganese concave or a bowl liner. As rock enters the top of the cone crusher, it becomes wedged and squeezed between the mantle and the bowl liner or concave. Large pieces of ore are broken once, and then fall to a lower position (because they are now smaller) where they are broken again. This process continues until the pieces are small enough to fall through the narrow opening at the bottom of the crusher.

4.3.2.3. DDC-Sizers

At MPS, those are the basic crushers that are used in the receiving hopper. They are manufactured by McLanahan, a world producer of drag chain feeders and DDC-Sizers.

They customise their design to meet industry specific needs. DDC-Sizers incorporate the basic concept of two rolls with teeth rotating either towards or away from each other. Crushing to the outside is required for products that are 76mm or finer. At MPS, this is not the case since our initial product is at 1000mm. The material that is already to size passes between the rolls or behind the rolls, thus minimising the generation of any fines. Plus-size material is grabbed by the teeth and pulled into the machine for reduction. The teeth pierce the individual pieces allowing the material to separate along inherent fracture planes. The speed of the rolls ensures minimum dust and fines generation. The action is represented in Figure 14 below.

Figure 14 DDC Sizers

Coal is then discharged onto the unloading conveyor, which conveys and discharges the coal onto the overland conveyor.

4.3.3. Conveyors

A conveyor includes all fixed and portable equipment capable of moving material in a continuous or intermittent fashion, between two or more points, along a fixed path. While the material may be delivered intermittently, the drive operates continuously. The movement of material can be horizontal, vertical, inclined, or any combination of the three.

4.3.3.1. Types of Conveyor System

There are so many kinds of conveyor in the market. Which one of them is most suitable to be used in this project has to depend on its functionality. Let us look at some of the common types of conveyor.

4.3.3.1.1. Powered Rollers

Powered rollers conveyors, straight or curved, are extensively used for heavy and arduous applications such as rolling mills and foundries. They are also an ideal medium in package handling for systems where it is necessary to stop, meter, or manipulate articles without stopping the conveyor. It is also an economical way of moving heavy loads in limited space.

4.3.3.1.2. Chain

Chain conveyors have been designed to cover many varied applications in industry. They employ several distinct patterns including twin chain, multiple chain, in-floor, on-floor and heavy duty overhead. They are particularly useful where high temperatures are

involved, and special designs with expansion joints and automatic spray lubrication are available.

4.3.3.1.3. Belt

Belt Conveyors are probably the most widely used of all the various types of conveying equipment. They are extremely versatile and there are many variations. The range varies from very small conveyors used in packaging machinery through to heavy duty conveyors used for bulk materials. They usually consist of moving single or multiple endless bands of material upon where the product sits, and is conveyed. The belts can take a straight path or can be twisted through more complex paths.

4.3.3.1.4. Slat

Slat conveyors are most suitable for use when the unit loads are beyond the capacity of belt conveyors, or where heat or other adverse conditions render the use of the latter impracticable. They are frequently fitted with chains having oversized rollers. The larger the roller diameter, by reducing the number of revolutions per roller, increases chain life and also allows the use of heavier chain sprockets. Slat conveyors are extremely versatile. Not only because their design and construction is simple but also because maintenance and tracking problems are minimal. They are also excellent for heavy loads and rough treatment.

5. Conceptual Designs

Below are a series of 5 proposed engineering solutions to clear the grizzly. Each design has its own features, advantages and disadvantages. Analysis of each design is required for a clear justification on which design is the most appropriate solution for MPS. The following sections describe the criteria and decision matrix results.

5.1.1. Design 1
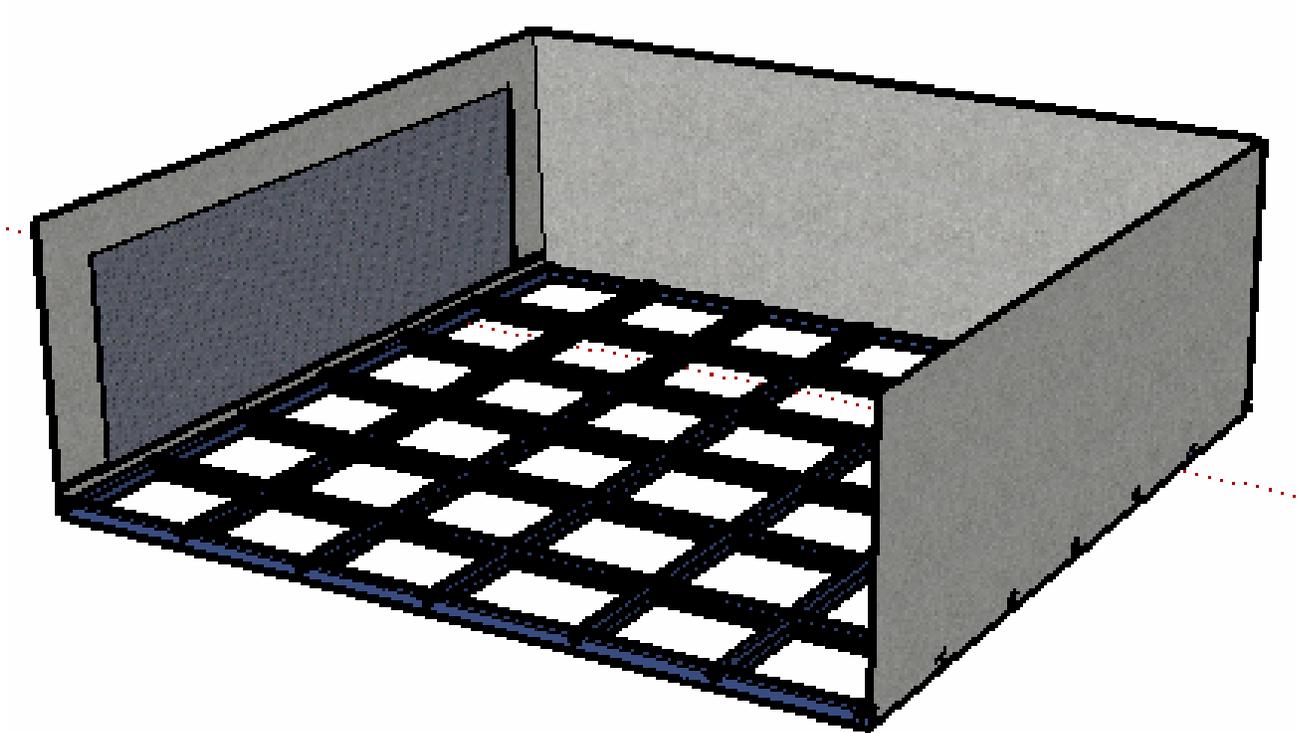
5.1.2 Design 2
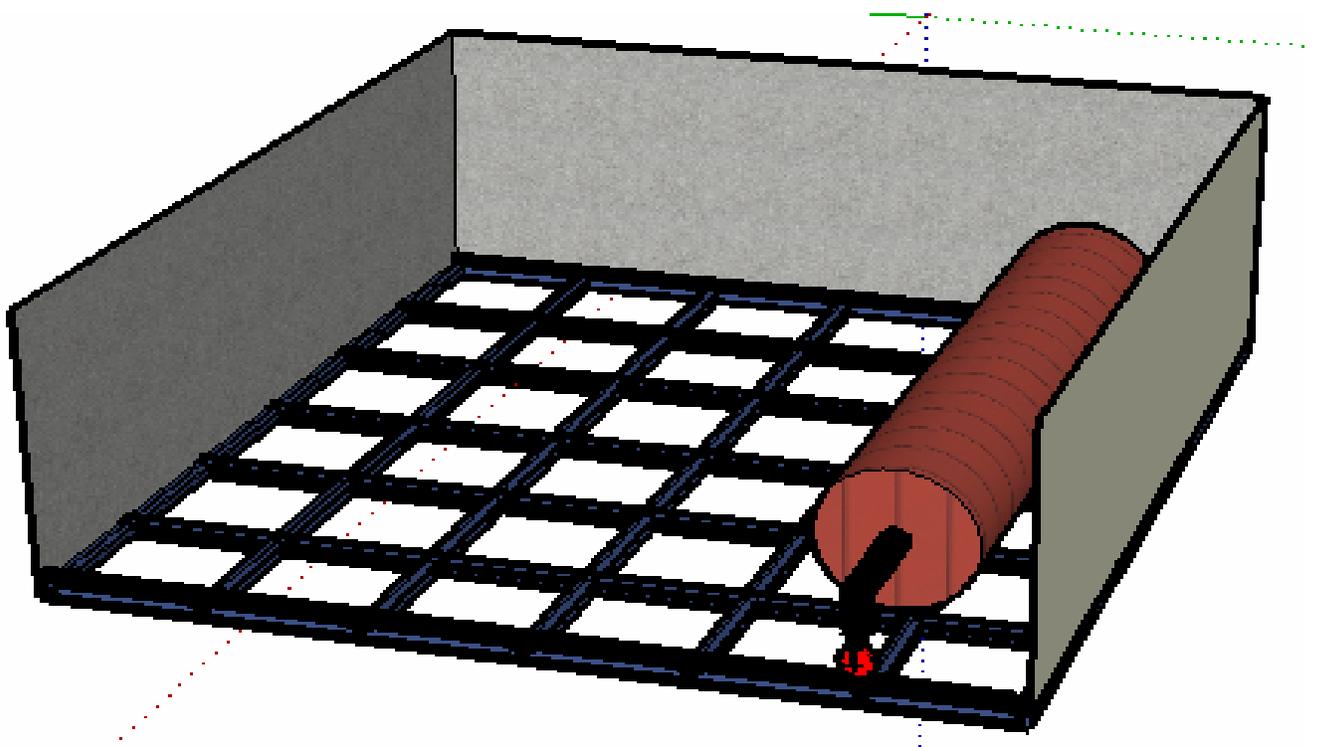
5.1.3 Design 3
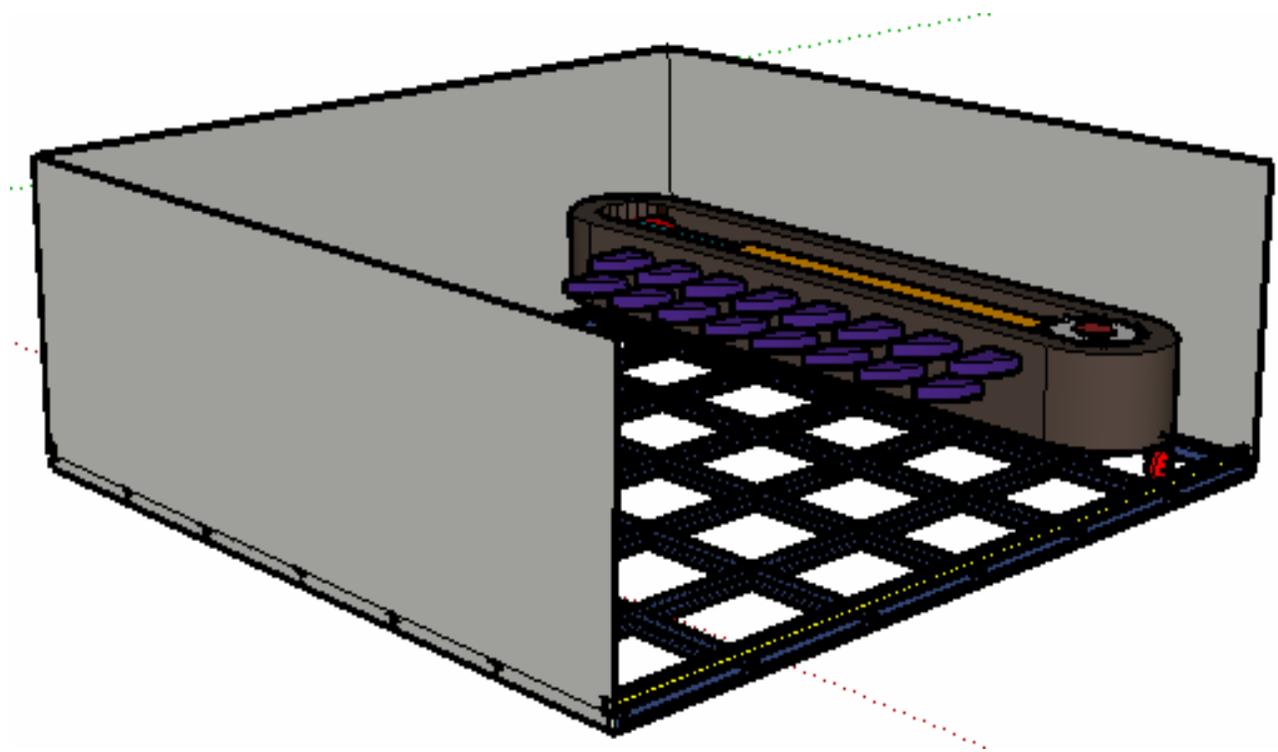
5.1.4. Design 4
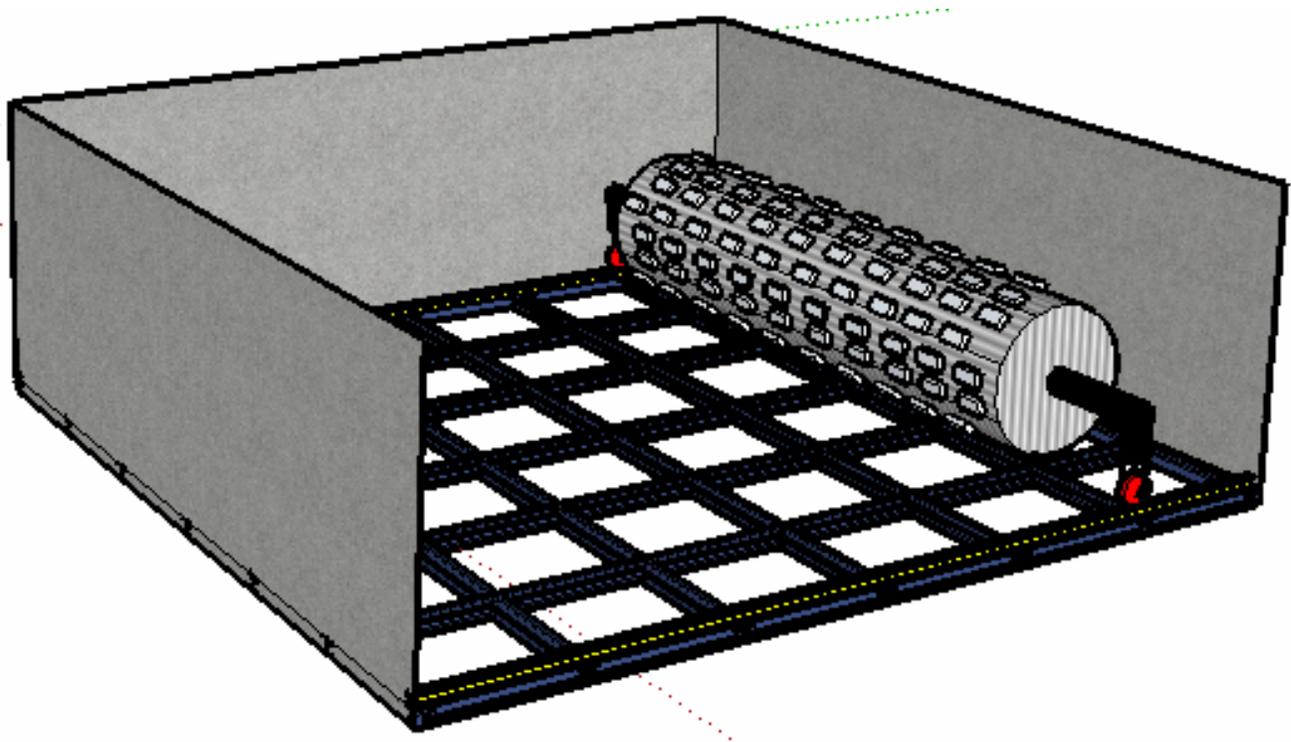
5.1.5. Design 5
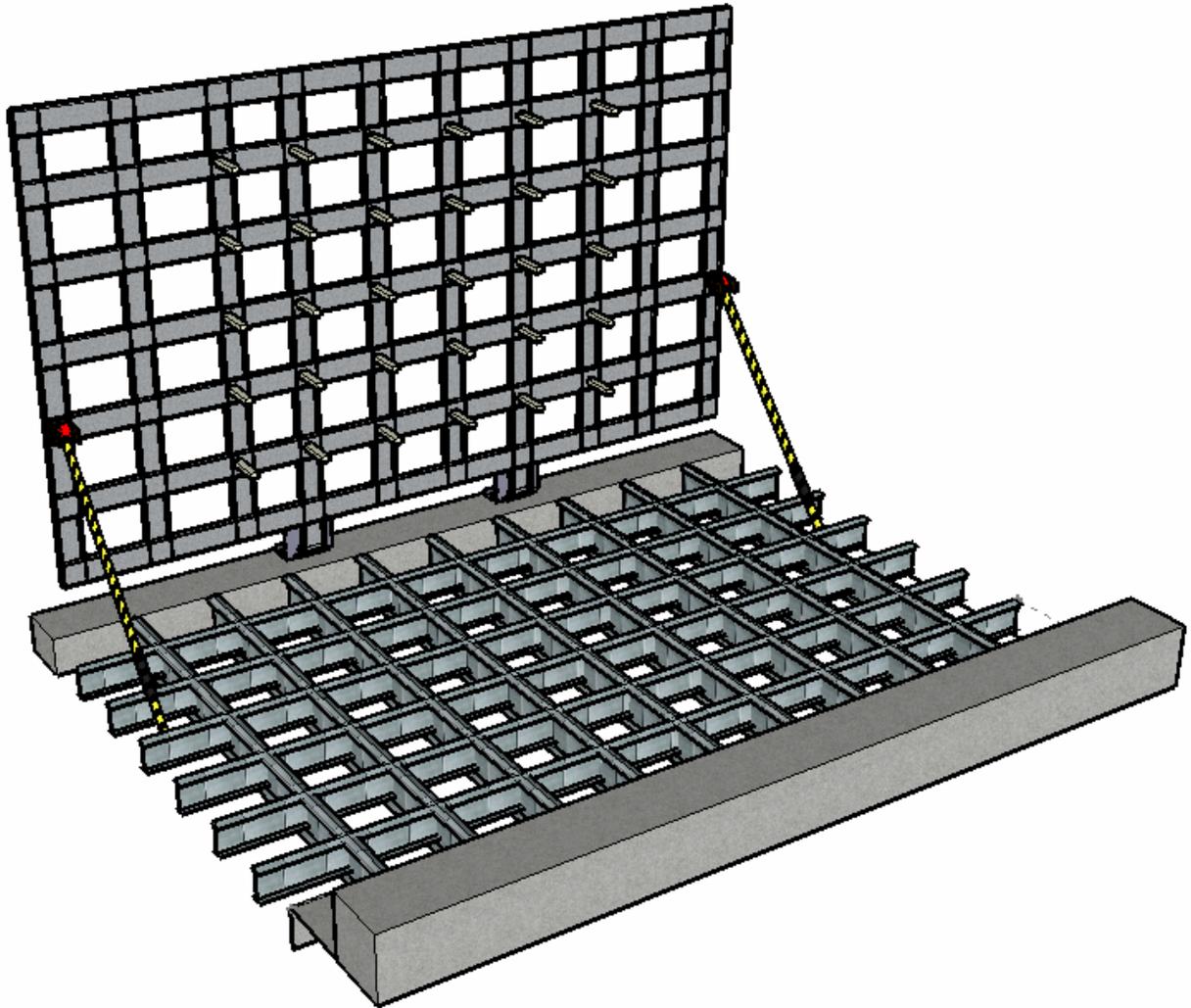
5.2. Decision Matrix Criteria

A decision matrix was utilized to uncover the best conceptual design from a range of potential designs nominated before. The decision matrix used to rate each individual design for the ROM grizzly was created based on a number of specific criteria. Each criterion had equal weighting within the matrix. All conceptual designs were given a score between zero and three for every criterion depending on how well the ROM grizzly design functions and capabilities would potentially perform. Each individual conceptual design was subjected to critical examination. This process enabled the discussion of the advantages and disadvantages of each proposal and located any potential problems the system may encounter on-site.

When we speak generally of design consideration, we refer to some characteristics that influence the design of any element, or perhaps; the entire system. The four criteria used in the decision matrix and their potential impacts on the final conceptual design selected are explained in detail below as, (1) ease of construction and installation, (2) functionality and effectiveness, (2) ease of operation and maintenance and finally, (4) the cost.

5.2.1. Ease of Construction and Installation

The potential overall size and weight of the mechanical system is a major consideration taken into account the decision matrix as it is critical to almost every aspect of the conceptual design. This factor mainly impacts whether there is sufficient space for the system to be installed. The size also, influences the manoeuvrability and mobility of the system, also affecting the cost of running and maintenance.

If the overall size of the system is too large, more power is needed to operate all moving parts and, therefore, will increase running costs. The weight of the system is also very important to consider. This aspect of the design is largely dependent on the size of the machine. The size of the framework where the machine actually sits on, especially if heavy materials such as stainless steel are used, is likely to provide the most significant proportion of the overall mass to the design. It is, therefore, considered that the larger the overall dimensions of the mechanical system, the heavier and then more costly the

machine will become. It should also be noted that the size of the system will impact directly on the clearing capacity of the coal on the grizzly. Weight is affected by size and, as such, impacts the overall time taken to complete a single cycle.

The overall dimensions of the system play a critical role in deciding whether the system needs a platform to sit on with a guide system or whether it should only be fixed to one side of the grizzly.

5.2.2. Functionality and Effectiveness

The second factor considered in the decision matrix is the functionality and effectiveness of the mechanical system. The functionality simply describes how well the design will perform the necessary task of clearing the grizzly from big chunks of coal. The ability to achieve stated goals or objectives - judged in terms of both output and impact - is what defines effectiveness. This criteria must take into consideration if the features included in the system will work together to accomplish the final goal. In our case, is the mechanical system proposed sufficient to automatically clear the coal on top of the grizzly?

The criterion also considers the reliability of the featured components used in the design. The more reliable the features are in the unit, the more likely they are to be continually working together in operation. Machinery maintenance costs will also be high if the system does not function as the featured components are supposed to, or if the components continually fail due to the life expectancy of the parts not reaching the minimum expected age. A design that is simply not practical due to an excessive number of features will cause an overall increase in size, weight and costs. This design will score poorly in the matrix as it is likely to not perform well during operation. However, a simple design that incorporates that incorporates the minimum number of necessary features has greater potential to work together without fault. Such a design is likely to score high in this area.

An effective design is also one that minimizes any wear and tear, and hence minimizes maintenance repairs. It even includes how the design fits in its surrounding environment.

So an effective design needs to clear the ROM with minimum stress placed on the grizzly itself and the cladding surrounding it.

5.2.3. Ease of Operation and Maintenance

User-friendliness describes how easy it is to operate and maintain the machinery. This criterion takes into account every thing to do with the operation, maintenance, setting up, and installation of the system - as well as - the easy of operation of the mechanical system itself. This is important to achieve for not only the smooth running of the mechanical system, but also for the cost of maintenance of the machinery.

MPS is more likely to accept the design if there is little trouble running and maintaining machinery, than if extra time and money is spent every fortnight, for instance, looking after the system. The easy of maintenance of the system must be also taken into account as the design will include a number of moving and functional parts that will eventually wear and require replacing. The easier these components can be replaced, the less time and cost will be required to be paid by MPS to restore the equipment to its working conditions.

MPS would rather a system that only requires the operator to press a 'Start' button and have a fully automated mechanical system that clears the grizzly. The idea of not having an operator running the system is crucial to the design, since it will save on operator costs.

5.2.4. Cost

The final design criterion that is used to rate the conceptual designs is the potential cost of the system. A cost of the design considers all aspects of the system from the construction, installation and commissioning, all the way to maintenance.

The biggest cost to be considered will be the construction of the system itself. This is because, during its construction, the mining process will have to stop since no ROM dumping can take place and, hence, for MPS – no power generation.

Other timely issues to be considered with cost are, (1) Can the mechanical system be constructed over the weekend (since no dumping of coal takes place then) and; (2) Is 48 hours sufficient time for the whole system to be installed?

More framework will be required, the larger the size of the unit. This structural frame is likely to be made from carbon steel to minimize the costs. The cost of the system will depend on the size, available functions and number of features of the individual components used in the design. The more features and the more available functions a component has, the more likely that the price for that component will be high.

Maintenance costs of the conceptual designs will also be considered. A large system will have many interdependent components interacting and will not be functioning correctly if one aspect of the system fails. The system will have components that will require replacing after a given lifespan. The longer the components will last, the fewer the components that are required to be bought and the lower the maintenance costs will become.

Generally, the components most likely to wear out quickly should be positioned so that access to the components is easiest if possible. The easier the maintenance is of these components, the less time will be takes to replace them and, therefore, lower cost of wages paid for the technicians to perform the necessary maintenance and costs associated with down time of the machinery.

The advantages and disadvantages of each design will now be considered and discussed.

5.3. General Analysis of each design

5.3.1. Design 1

Advantages	Disadvantages
1. Simple process	1. Too heavy
2. Not many parts	2. Results in stress on grizzly and cladding
3. Low maintenance costs	3. Too expensive to weld the big structure

This design involves the use of a big welded rectangular steel part that is supported through its centre by a heavy duty cable that is fixed outside the cladding through an external drum connected to a motor. The operator activates the machine through a switch that lets the part fall freely to a horizontal position that is low enough to hit the coal and break it into pieces, without touching the grizzly. It only uses the reaction forces of the I-beams to apply an opposite forces to break the coal. After a programmed time frame the motor starts and rolls the cable back through the drum, and the part retracts back to its original vertical position.

5.3.2. Design 2

Advantages	Disadvantages
1. Easy to design	1. Complicated installation
2. Produces high crushing force	2. No effective results
3. Not many parts in moving body	3. Overall heavy structure
	4. Places stress on grizzly
	5. Requires complex guide system
	6. High power consumption

This design involves the use of a big roller that is half filled with water to lower its centre of gravity and increase its weight, making it effective at crushing. The roller uses its momentum to run slightly elevated along the grizzly, crushing the coal against the I

beams. The roller is supported by a guide system, involving rails on either end, and a wheel on either end fixed on the rails. The guide system is powered by a motor, and transmits forces through a complicated gear system to drive the roller up and back the grizzly. Since the roller is heavy it involves a lot of power to the move the structure, and hence, not enough power is transmitted through torque resulting in a slow cycle time.

5.3.3. Design 3

Advantages	Disadvantages
1. Simple to construct	1. Complicated installation
2. Very effective	2. High maintenance costs
3. Doesn't occupy much space	3. Could jam as a result of vertical forces
4. Relatively cheap to construct	4. Chance of wheels falling off track from sand and dirt
5. Very effective in removing excess coal	5. Contains many moving parts

This design is very similar to that of a trench digger that is installed in a horizontal position, supported on a guide system, like that of the previous' design, that takes the structure up and back the grizzly. The structure involves a chain with a rotating gear fixed to a motor on one end, and a support sprocket on the other end so the chain is fully tensed and contains a set of teeth fixed onto the chain, that are moving at a high speed. The overall structure is relatively light, and so, the time it takes the digger to go up and back the grizzly is fairly short, resulting in effective results.

5.3.4. Design 4

Advantages	Disadvantages
1. Operates in three dimensions (3D)	1. Complicated to design and install
2. Produces very effective results	2. Occupies a fair bit of space
3. Fast acting, hence short cycle	3. High rpm results in lots of wear and tear
4. Places no stresses on grizzly	4. High maintenance costs

This design involves the use of a fast light rotating roller, with pics on the outside of the roller specifically designed to break the coal. It is supported on a guide system with rails on either ends that guide it up and back the grizzly. It's a fairly light structure and so, most the torque is used to drive it fast, and so the cycle time is short. It's also rather effective in crushing the coal, but again, at fast speeds, one could expect a lot of wear and tear, and high maintenance costs.

5.3.5. Design 5

Advantages	Disadvantages
1. Not many moving parts	1. Complex hydraulic system needs to be installed
2. Easy to construct and install	2. Pics need regular replacing
3. Relatively cheap, simple and easy maintenance	
4. Places no stress of any sort on the grizzly	

The last and final design, involves the use of picks bolted to a steel frame structure. It is pivoted on a hinge, supported by two hydraulic rams on either end, designed to lower the structure at a specified speed, until it rests in a horizontal position, and then pushes it back up to its vertical position. The structure is fairly light. Therefore, not much force is needed in the hydraulic rams to bring it back up. There are not many moving parts and so maintenance costs are at a minimal and the structure does not come in contact with the grizzly and so it doesn't place any stress on it either

5.4. Decision Matrix

Each design was analysed by me and a number of engineering students. Ratings were applied to each design from the following criteria:

3: Good

2: Satisfactory

1: Poor

0: Very poor

	Design 1	Design 2	Design 3	Design 4	Design5
Ease of Construction and Installation	1	1	2	2	3
Functionality and Effectiveness	1	1	3	3	3
Ease of Operation and Maintenance	2	2	2	2	3
Cost	1	2	3	3	3
Total	5	6	10	10	12

Based on the above analysis, design 5 is clearly the chosen design. This is because it scored the most on the matrix with more advantages than disadvantages. In the next chapter, the components of design 5 will be further detailed and developed.

6. Main Components of Design

6.1. Main Frame

The main frame (Figure 15 and Figure 16) is an 12x7m steel rectangular structure supported by two hinges at its base and covers approximately half of the total grizzly area. The steel sections are 380 PFC parallel flange channels that interconnect at right angles forming smaller squares. There are seven horizontal sections by seven vertical ones. The frame has 30 picks bolted to it that are used to crush the coal. The picks are bolted at where the steel sections inter-cross for maximum support since it is the area where the reaction forces from the coal are at a maximum.

A 380PFC section weighs 55.2kg/m and hence the structure has a total weight of approximately 8.9 tons, with its two bases welded to two hinges that are welded on the other side to a hydraulic cylinder. The frame pivots through its base to a maximum 90 degree swing from its upward vertical position. The speed of the swing is controlled through the hydraulic system that is installed behind the shed, and the details of its operation will be discussed shortly.
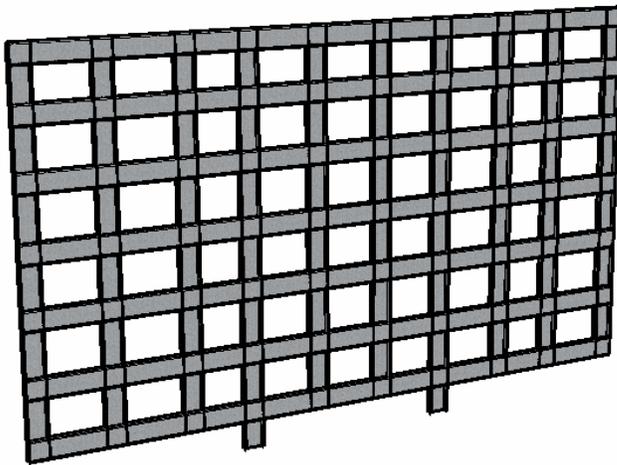
Figure 15 Main Frame Member
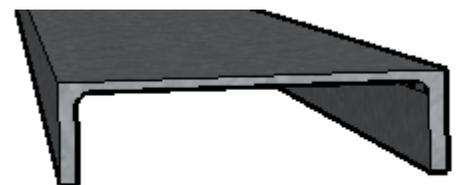
Figure 16 Frame

PFCs have parallel flanges and their material is spread further from the principal axes, resulting in better utilization and accordingly, a reduction in linear mass. However, due to optimisation in section design, the linear mass of PFCs is lower than that of the old sections and considerably improved section properties are obtained about the y-y-axis. This offers an enhanced load-carrying capacity, as higher design stresses can be used.

Other advantages of PFC-sections include the use of standard washers instead of tapered washers for bolted connections, fixing of bracing elements to the inner flange surfaces for built-up columns and beams and simplified connection detail.

6.1.1. Advantages of PFC-Sections

Weldability

PFC-sections may be welded using any of the standard metal arc and resistance welding processes, usually without any special precautions.

Protective coatings

When choosing a rust prevention method for a steel component or structure many technical factors including the environment, stress during transport, storage, fitting or erection must be considered. Adequate preparation of the substrate is of vital importance to the ultimate success of the coating, as is the method of application. Paint, hot-dip galvanizing or duplex coatings (zinc plus paint) can be specified for corrosion protection, depending on the aggressiveness of the environment. Choice of the protective mechanism is considered to be the responsibility of the specifier, fabricator or end user.

Applications

PFC-sections can be used for all applications where taper flange channels are used, i.e. for beams and columns, purloins, chassis structures and other fabrications.

Surface quality

Surface defects up to a maximum depth of 3% of the nominal thickness shall not be considered as a reason for rejection. Larger surface defects may be removed, providing the nominal thickness is not reduced by more than 7%.

6.2. Hydraulics

Hydraulics is a branch of science and engineering concerned with the use of liquids to perform mechanical tasks. It is part of the more general discipline of fluid power. The medium for the transmission of fluid power in this instance is incompressible hydraulic fluid. The idea behind using a hydraulic and not a pneumatic system in our case is that the medium (hydraulic fluid) can be pressurized to higher levels than air, and hence generate a greater force at the actuators. Hydraulic systems are generally applied in situations where a large force is required, which is needed to lift the main frame. Although the speed of application of the force is much slower than in pneumatic systems, there is sufficient time, roughly seven minutes before the next load is ready to dump.

6.2.1. Hydraulic Actuators

An actuator is an output device for converting the supply energy into motion. The speed and direction of this motion is controlled by final control elements e.g. directional control valves and control valves. Hydraulic actuators get their power from pressurized hydraulic fluid, which is typically oil. The cylinder consists of a cylinder barrel, in which a piston connected to a piston rod is moving. The barrel is closed by the cylinder bottom and by the cylinder head where the piston rod comes out of the cylinder. The piston has sliding rings and seals. The piston divides the inside of the cylinder in two chambers, the bottom chamber and the piston rod side chamber. The hydraulic pressure acts on the piston to do linear work. The force exerted by the cylinder would be in proportion to the area of the piston the pressure of the compressed air entering the cylinder. The speed of travel of the piston would be governed by the rate of flow of the compressed air and the internal and external resistances the movement must overcome.

For this design, the hydraulic system needs to be able to lift the 8.9 ton structure, and for that reason, a hydraulic system is more appropriate than a pneumatic one. A double acting cylinder would be installed instead of a single acting one. The difference is, in a single acting cylinder, hydraulic pressure acts on one side of the piston. This allows for only very small force applications in the return stroke, which would not be sufficient enough to crush the lumps of coal caught by the grizzly. In a double acting cylinder, the forward and return strokes are force producing working strokes. The ports on either side of the cylinder act as supply or exhaust ports, depending on the direction of motion. This is relevant to our design, since we need large forces in either direction, firstly to crush the coal as the frame is lowered, and secondly to lift the 9 tonne structure.

The curvilinear motion of the frame as it comes down means that the hydraulic cylinder (Figure 17) needs to be able to pivot at both its free ends. At the bottom, the head is fixed to the rear hinged mount, and at the top, is attached to the cover via a pin, the cover being welded to the frame.
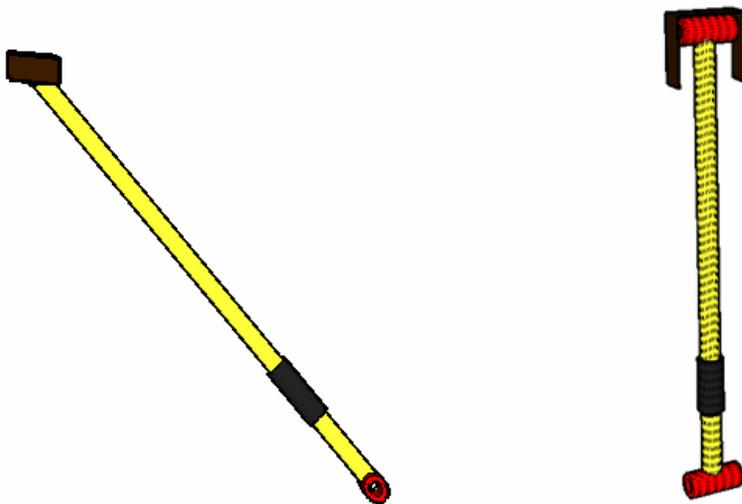
Figure 17 Hydraulic Cylinders
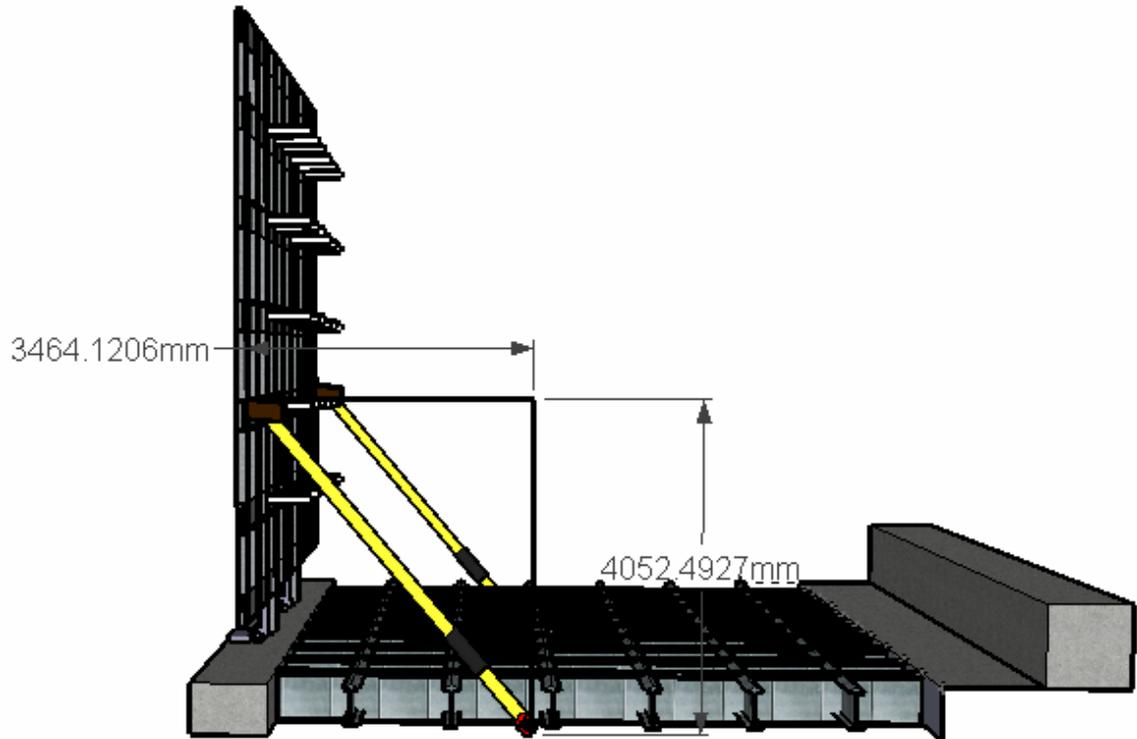
Figure 18 Hydraulic Actuators Fully Extended

Figure 18 shows the location of the hydraulic actuators. The dimensions could be rounded down, so that the bottom of the cylinder is at a horizontal distance of 3460mm from the main frame, and a vertical distance of 4000mm from the bottom. Applying Pythagoras theorem allows us to determine the total extended length of the cylinder, being 5300mm. This should very reasonable, since the closer the actuators to the frame, the more force that is required to lift the structure. Also, the further away from the frame, the longer the piston rod needs to be to compensate for the extra distance. This would place tremendous stress on the actuator and could result in the buckling of the piston rods.
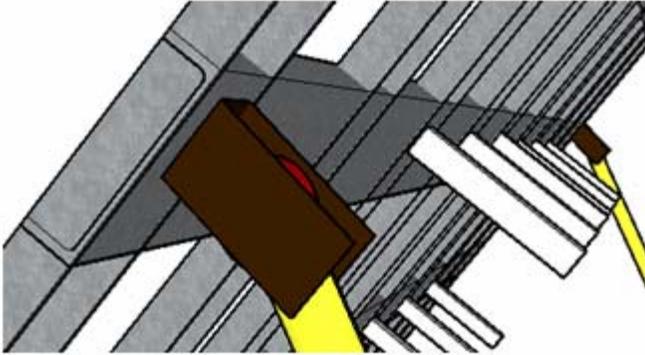
Figure 19 Angle changes to Actuators

Figure 19 illustrates how the welded cap changes angles as the frame gets lowered. It goes from a complete horizontal position when the frame is upright to a complete vertical position when the frame is completely horizontal.

6.3. Picks

Picks (Figure 20) are used in the mining industry to break large lumps of minerals. They have different shapes and lengths, depending on the type of   mineral and the situation they are exposed to. They are usually made of high carbon steel.

I was advised during my MPS site visit that square end picks would be sufficient for our purpose, since coal is relatively a much softer mineral than rock

.
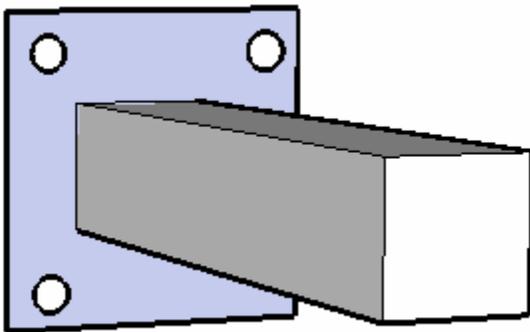
Figure 20 Square End Pick

The picks are 100x100x500mm RHS (Rolled Hollow Sections) with square ends, that are bolted to the frame for easy replacing. The picks are likely to experience the most wear and tear as a result of direct contact with the coal caught on the grizzly, and therefore, for convenience, bolting them to the frame allows for easy replacement. The picks act as hole punchers. They drill a hole in the lumps of coal and, since coal is a brittle material, it breaks it into smaller pieces that are small enough to go past the grizzly. The picks don't come into any contact with the grizzly itself. They are concentrated more in the central area of the frame, since most coal dumping takes place in the middle of the grizzly, and is where most blocking takes place. For that reason, all picks are of equal length. There should be no concern about large lumps being thrown all the way in the back, and if that was the case, there should be no problem with the picks punching a hole right through it. The picks don't experience much stress, although they experience the most deformation (See Appendix F), as a result of their direct contact with the coal.

6.4. Hinges

Hinges are flexible joint mechanisms that provide support to and allow for the turning or swinging movement of the object to which they are attached. They consist of two leaves attached to the object and to frame of object. A set of knuckles rest between two leaves, knuckles connect leaves to one another. A pin is inserted through the knuckle to secure hinge in place. Determination of the pin size can be found in Appendix D.

The main function of the hinges is to support the frame at its base, where they are both welded together. It allows for a 90 degree swing of the frame, from its vertical through to its horizontal position. This is the best design for the hinge, since it places minimal forces on the pin. The reason is that the frame is supported by the hydraulic rams the whole way, the pin only allowing for the swing motion. ANSYS (Figure 21) also showed minimum stress and displacement at the support of the frame, where the hinge is installed.
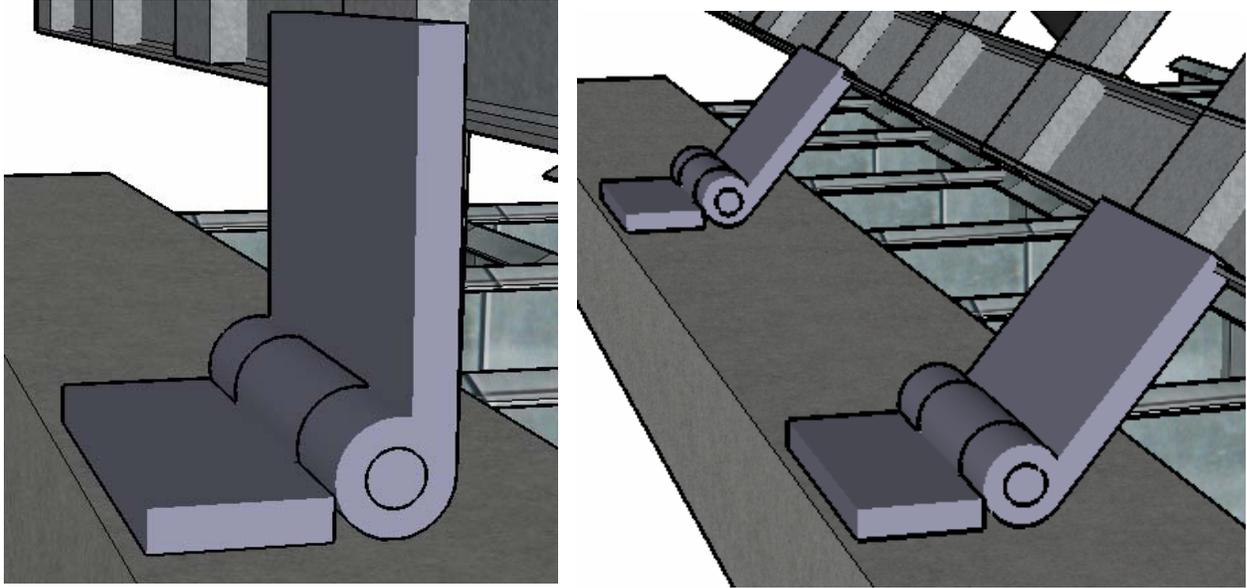
Figure 21 Hinge Stress and Displacement

There are several factors to consider when specifying hinges:

1) Weight of the structure the hinge is supporting
2) Other factors or loads (external) that need to be considered
3) How far must the frame swing
4) What specifications must the hinge meet

The hinge should require minimal maintenance, that being lubrication only. It is recommended the hinge to be welded to the frame, and bolted to the grizzly deck for extra support.

6.5. Determining how much force is required to break the Coal

Yield strength is defined as the tensile load at which deformation or size alteration is first detected (Suresh 1998). Newton's third law states that for every action there is an equal and opposite reaction, and so, deflection of the beam would be directly related to the reaction force from the coal unto the beam. That is why I need to examine how much force is needed to break a piece of coal. From that data, I can work backwards and determine the bending moment exerted at the tip of the beam, and hence, the total deflection of the beam. Research work in this area has, however, been hindered by the

difficulties involved in testing coal specimens for the determination of their mechanical properties. These difficulties arise from the very nature of the coal. Coal is a sedimentary deposit with distinct bedding planes and usually has two near-orthogonal cleat planes. In addition, it intrinsically contains many cracks and fissures. The multiplicity of the cracks in coal is reflected in its brittle nature and low strength values (Bhagat 1985; Powell et al. 1981). In the past, different methods (Evans 1961) have been used to determine the strength of coal. Tensile strength is defined as the pull stress (in force per unit area) required breaking a given specimen. Specimen size effect is important in determining the tensile strength of coal. Evans (1961) showed that the strength of coal specimens was related to the thickness of the specimen in the form:

$$tensile.strength.\alpha(thickness)^{-0.23}$$

There is no real raw data on how much force in Newton would be required to break a piece of coal. There are various types of coal with different amounts of sand, clay, moisture etc. An accurate approach would be to go on to the MPS site, and obtain random specimens of coal. This takes care of the components of the coal itself and eliminates any errors. The other limitation is to arrive to a relationship that basically states, "*An X amount of coal in kg would need an X amount of force in Newton to break, and therefore a 10 X amount of coal in kg would need a ?X amount of force in Newton to break*". We know from basic material properties that the relationship is not going to be linear; in fact, it's more likely to be an exponential curve, but the question is, by what factor??

Thus, I decided to obtain a small piece of coal and carry a deformation (brittleness) test on it in the lab. This would be a start for me to examine axial force (compression) impacts on coal. The coal I selected is basic wood coal with properties that would be considerably different to the hard coal that is mined on the MPS site. One advantage is that, at the end of the day, coal is a relatively soft brittle material and the picks designed should have no problem penetrating through the coal and breaking it. An average figure obtained for the reaction force from the coal is only an indicator of how much deflection would be taking place in the beam. I utilised a coal specimen that measured 256x195x193mm and weighed 34.3g and is shown in Figure 22 below:

Figure 22 Coal Specimen for deformation test

The test was performed using a Multi-Purpose Hydraulic Wedge Grip, model MTS 647 (Figure 23). Axial grips can be used for both static and dynamic material testing applications. Specimens are clamped and released using hydraulic oil. Since the wedge housing retracts upon release specimen repeatability is insured. The clamping pressure and rate of closure are adjustable. These grips are designed to maintain a constant clamping pressure on the specimen. Interchangeable wedges increase the flexibility of these grips.

Figure 23 Multi Purpose Hydraulic Wedge Grip, model MTS 647

The specimen was inserted and applied with a compressive axial load of 2mm/min. The screen monitored the deflection levels of the specimen, and plots load applied in Newton's versus extension (deflection) in mm.

The specimen (Figure 22) was left to be completely crushed and this could be seen through the fluctuations of the graph and finally by how it levelled off.

Figure 24 Crushed Coal Specimen

A more accurate approach involves using a piece of coal and to examine its behaviour when placed vertically. That is a standard for measuring the brittleness of solid rocks. The specimen is trimmed at its edges using a saw so it's straight, and is inserted into the machine. Two specimens were examined, the first measured 30x125.10mm and the second specimen is only shorter at 30x32.50mm. The diameter 30mm is only an approximation since the tip is more triangular than circular, but the triangular area will be used in the calculations since that is more accurate. The two samples are shown below:

Figure 25 Coal Specimen Vertical Deformation Test
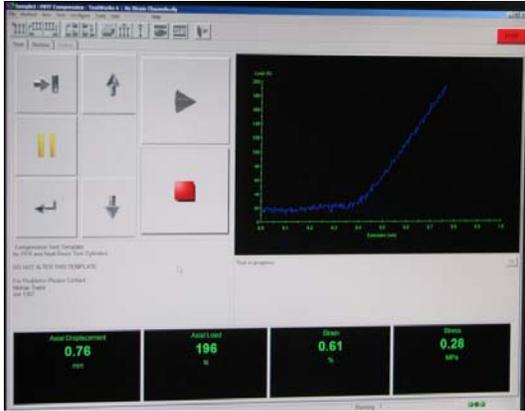
Figure 26 Vertical Coal Deformation Test Procedure

The same procedure (Figure 26) previous one is applied. The screen monitors the load applied in Newtons and plots it against time or deflection of the piece, depending on the choice.

Figure 27 Vertical Cracks in Coal Specimen

You can see from Figures 26 and 27 the long vertical cracks running through both specimens. A monitor measures the behaviour of the specimen under axial load. The load is applied uniformly on the surface, whereas with the mechanical design, a hole is punched right through the lumps of coal. The type of coal specimens used in this experiment do not relate to the type of coal mined at MPS. Also with the design, the pick has a smaller cross-sectional area generally relative to the lumps of coal, exerting a much higher pressure, resulting in a lower force required to break the coal. In our case, a much higher force is required since a lower pressure over a larger area is exerted on the coal. This could be used as a bench-mark value, meaning, the force calculated here would be guaranteed to break the coal on the grizzly. The result of one of the samples is shown below:
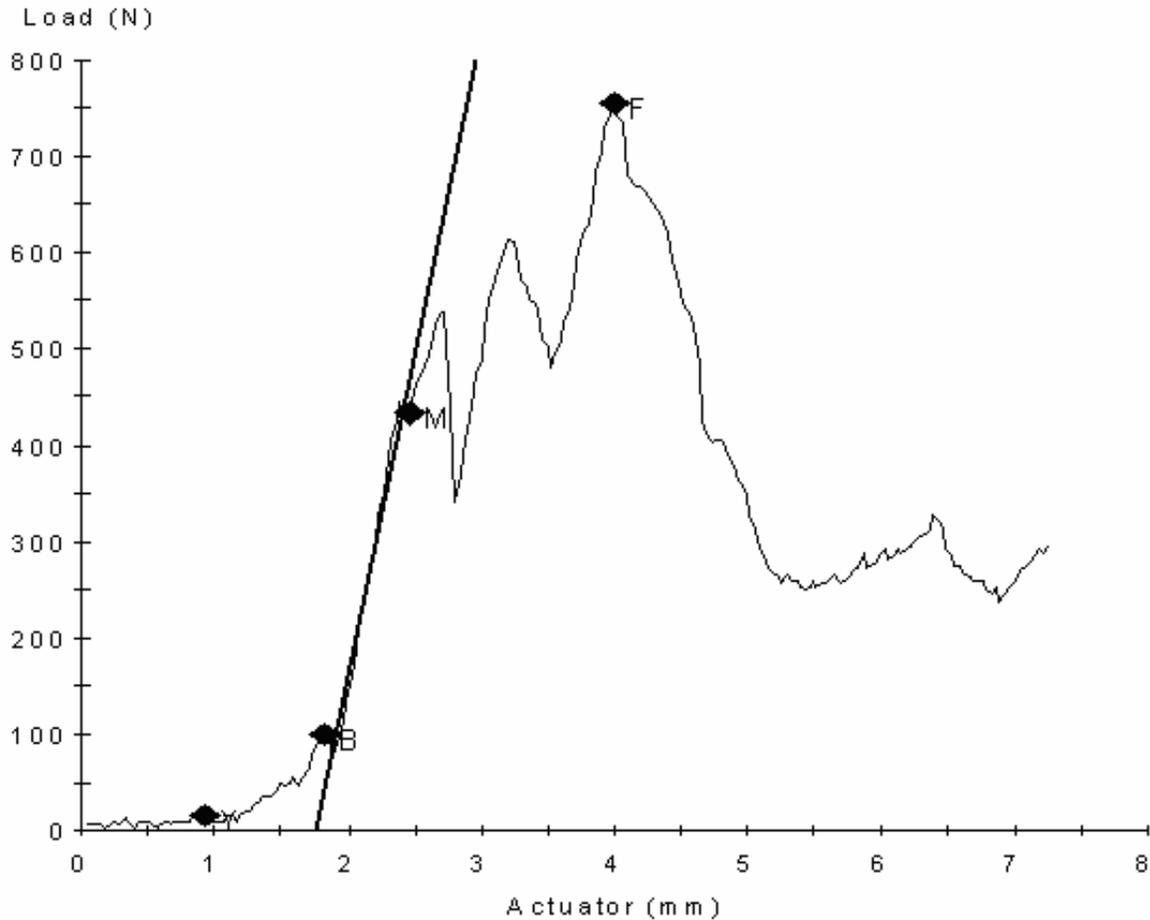
Figure 28 Coal Deformation Test Result

The graph in Figure 28 above shows the Load in Newton against the Actuator / deflection in mm of the coal specimen. As the load on the specimen increases, the deflection increases. The load increases until it reaches 530N and then drops back to roughly 350N. This is because as the load is applied, the specimen is uneven at its surface, and so more force is applied on one end of the specimen than the other. As the higher end is chipped off, and the surface evens out, the load starts increasing again now that it's applied uniformly, until it reaches 600N and then drops again to 450N. This means the specimen has cracked, and so a lower force is required to produce a deflection of 2mm/min. The load increases again until it reaches its peak at 755N, after which the specimen has fractured, and eventually levels off.

Detailed results of the specimen were also produced by the program and are shown below:

Specimen Results:

Name	Value	Units
Specimen Height 1	32.50	mm
Specimen Height 2	32.50	mm
Specimen Height 3	32.50	mm
Diameter 1	30.00	mm
Diameter 2	30.00	mm
Diameter 3	30.00	mm
Area	706.86	mm^2
Peak Load	755	N
Peak Stress	1.07	MPa
Elongation at Peak	1.85	mm
%Strain At Peak	5.69	%
Compression Modulus	31	MPa

Table 4 Coal Deformation Test Results Data

The above results in Table 4 demonstrate clearly that the maximum force required to break the coal is 755N, and the compression modulus is 31MPa which was also advised and confirmed to me by the engineering manager (David Hunt) at MPS. This data will be utilised for the simplification of the project.

If the funds and means were available, proper samples could have been collected from the MPS mine site and taken to a research facility lab where they could have been sized according to certain standards and the deformation tests applied to them. Only then, could a realistic or more correct number be obtained. Usually when these cracks are observed, the axial load drops drastically and the graph levels off.

7. Detailed Design Analysis

7.1. Main Frame Beam Deflection

Deflection is a term that is used to describe the degree to which a structural element is displaced under a load. The deflection under a load is directly related to the slope of the deflected shape of the member under that load and can be calculated by integrating the function that mathematically describes the slope of the member under that load.

A beam often requires a larger cross section to limit deflection than it does to limit stress. Hence, many steel beams are made of low-cost alloys because they have the same modulus of elasticity and hence the same resistance to elastic deflection as stronger, high cost steels (Juvinall & Marshek 2005).

There are various ways of calculating deflections in beams namely through integration, area moment method, use of singularity functions and various other methods. The method I will use to analyze the deflection in the beam structure will be the strain energy method, since it is used to determine the response of a structure to loads.

Strain energy is a measure of the energy absorption characteristics of a material under load up to fracture. It is equal to the area under the stress-strain curve, and is a measure of the toughness of a material. The external work done on an elastic member in causing it to distort from its unstressed state is transformed into strain energy which is a form of potential energy. The strain energy in the form of elastic deformation is mostly recoverable in the form of mechanical work. If the material is perfectly elastic the strain energy is equal to the work that must be done to produce both normal and shear stress. Once the stress that caused the strain is recovered, the strain energy is recovered. The recovery is total for perfectly elastic material and partial for plastic material due to dissipation.

The strain energy density or work per unit volume is actually the area under the curve of the graph stress VS strain as shown in Figure 29 below:
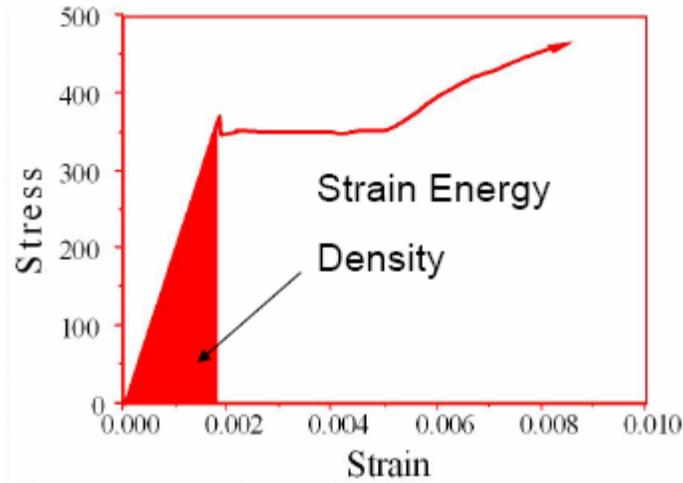
Figure 29 Strain Energy Density

In our case, I assumed the beam to be a cantilever beam with one end fixed and the other end with free load acting on it. The only load considered is at the furthest end since this is where maximum deflection is most likely to take place. For simplification of the calculation, only one beam was analysed as an individual structure instead of the whole frame structure.

Consider the cantilever beam shown in Figure 30 below:
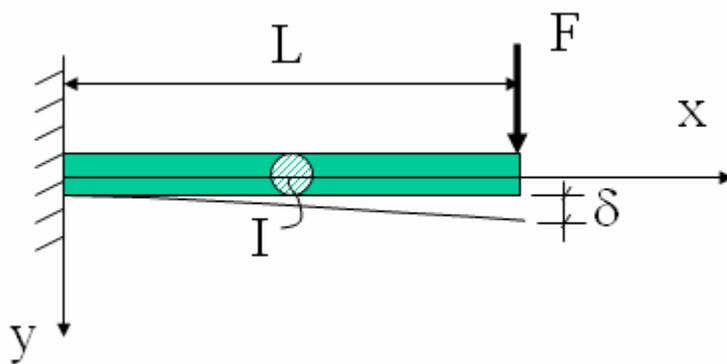
Figure 30 Cantilever Beam

The main governing equations are the following:

$$M = F(x - L)$$ (eqn 2)

$$U = \int_0^L \frac{[F(x-L)]^2}{2EI} dx = \frac{F^2 L^3}{6EI}$$ (eqn 3)

External Work, $W = \frac{1}{2} F \partial$ (eqn 4)

External Work = Strain Energy

$$\frac{1}{2} F \partial = \frac{F^2 L^3}{6EI}$$ (eqn 5)

Rearranging for ∂ to give:

Deflection $\partial = \frac{FL^3}{3EI}$ (eqn 6)

Where: M = Moment force (N/m)

U = Strain Energy (J)

F = Axial load (N)

L = Original beam length (mm)

W = External Work (J)

E = Young's Modulus of Material (MPa)

I = Moment of Inertia (mm^4)

A Matlab script Appendix E has been done to calculate the deflection and stiffness of the assumed cantilever beam with a load W at its free end using the strain energy approach and the equations derived above. When the beam specifications are inserted, a beam deflection of 1.59mm which is very small it could be assumed to be negligible.

7.2. Finite Element Analysis

Finite Element Analysis (FEA) is used in the design to mimic and model the behaviour of a given structure using small elements in either 2D or 3D systems. Computer analysis of these elements can show the designer specific critical information such as stress, strain,

temperature and pressure at given points in time at any place within the system. The accuracy of the results that are received by the designer is dependent on the relevant information entered into the system. This should always be based on sound engineering judgement.

Structural FEA was performed to check some simple situations that may be encountered in general operation. The main check was to examine the self-weight of the overall system. By calculating the stress and strain of the overall system when the effect of gravity is considered it will be seen where the design has been under or over designed. The stress through the picks and frame will take most of the weight of the system and are therefore considered to be the critical components relating to stress for the design.

A full FEA report has been attached in Appendix F for detailed review. All the relevant modelling assumptions have been made to make the simulation as simple as possible. A more detailed FEA on the hinge and hydraulic rams would have revealed more results, but the general locations of maximum shear and stress won't be any different.

7.3. Hydraulic System Design Considerations

An important consideration, especially with the larger loads applied by the hydraulic cylinders, is the buckling of the piston rods (MEC3303 2006).

When a forward force is exerted by a hydraulic cylinder, the piston rod is in compression and would behave in a similar manner as a loaded column. If a poor selection of piston rod material, and/or a small diameter of rod is made the piston rod could fail due to buckling. It is not practical to make the piston rod as large as possible (to prevent buckling) as you would remember that the force on the return stroke is influenced by the area of the piston rod [Force = Pressure x (area of piston – area of piston rod)]. Hence to optimize the diameter of the piston rod, i.e. large enough to prevent buckling yet small enough to maximize the force on the return stroke, careful attention must be given to Euler's Buckling Equation.

$$Pcr = \frac{\pi^2 E.J}{L_e^{\,2}}$$
(eqn 7)

Where: Pcr = critical buckling load (N)

E = Modulus of Elasticity (Pa)

J = second moment of area of rod (m^2)

L_e = free (equivalent) buckling length (m)

Therefore, the maximum safe working load on the piston rod is given by:

$$P = \frac{P_c}{FOS} \quad P = \frac{P_c}{FOS}$$
(eqn 9)

Where: FOS = factor of safety

7.3.1. Components of the Hydraulic System

The hydraulic system for raising and lowering the frame comprises a hydraulic piston and cylinder assembly with one end attached to the frame and the other end mounted to the side of the grizzly, below the I beam. A remote control station has a hydraulic pump, a reservoir, and a control for operating the pump to control frame movement. Hydraulic lines connect the control station with the piston cylinder assembly. Check valves in the hydraulic lines stop the dropping motion of the frame in case of loss of hydraulic pressure. A controlled return free fall valve is also disposed in the hydraulic lines to selectively restrict the flow of the hydraulic fluid.

When the assembly is in its retracted position, the frame is in its vertical position. The assembly can be fully extended to tilt the frame at a 90 degree angle so it lays horizontally parallel to the grizzly beneath it. Now, as the frame comes up, its weight exerts a force that opposes the motion of the cylinder, and if the hydraulic force was to be released, the frame would fall freely to its horizontal position. Also, as the frame comes

down, it exerts a pushing force on the piston and the piston rod, tending to accelerate its movement. In other words, if the frame is lying not horizontal flat, only the hydraulics would prevent it from falling freely.

As a precaution against accidental frame free fall, for example in the event of an unexpected loss in hydraulic pressure, the mechanical system installed requires a safety system to prevent free fall by blocking the hydraulic fluid and locking the cylinder and piston assembly. Also, it is important to be able to lock the frame in any intermediate position. Furthermore, it is important to maintain control and provide for user safety by assuring locking of the frame whenever the system is in maintenance and not in active mode.

Controlled return free fall, or gravity induced lowering of the frame, is desired for between both the vertical and horizontal positions, since it eliminates the work required to pump the frame back down.

As a safeguard against unintentional falling of the frame when it is in its vertical position, it is common practice to fit flow restrictors in the ram ports and so limit the speed at which the ram piston can move, or to fit lock valves which completely stop fluid flow and thus piston movement and have to be positively moved off their seatings before the ram can be extended or retracted. An ideal solution would be to use a combination of flow restrictors and lock valves.

7.3.2. Hydraulic Circuit
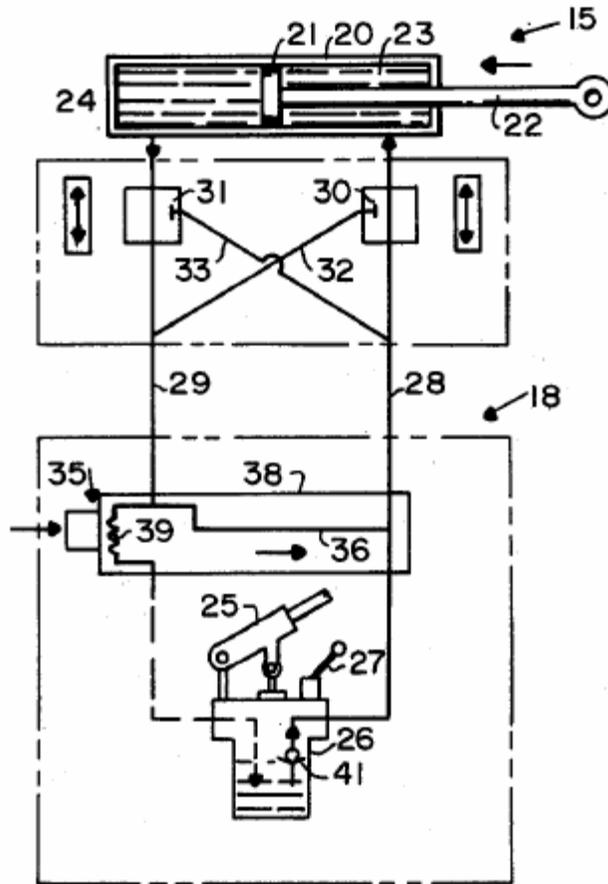
Figure 31 Hydraulic Frame Tilting System

Explanation of Hydraulic Circuit:

The hydraulic frame tilting system comprises two hydraulic piston-cylinder-assemblies **15** each having a cylinder **20,** a piston **21**, and a piston rod **22**, which are controlled from a single unit **18**, as shown in Figure 32. I shall describe only the operation of one system **15**, although an identical one is installed on the other side of the grizzly.

The cylinder **20** has an upper right hand-section **23** disposed above the piston **21**, for receipt of pressurized hydraulic fluid, and a lower left-hand section **24** disposed below it. The control unit **18** comprises a single hydraulic pump **25** with a reservoir **26** for storing hydraulic fluid. The pump **25** is connected to the conventional three piston valve **19** which is controlled by a moderate selector lever **27**, having three pistons: up, stop and down.

Connecting the hydraulic piston-cylinder assemblies to the control station **18** is a circuit of hydraulic lines. The pump **25**, through the valve **19**, is connected to the upper cylinder section **23** by a first hydraulic line **28**, and to the lower cylinder section **24** by a second hydraulic line **29**. A first pressure controlled check valve **30** is disposed along the first line **28** between the upper cylinder section **23** and the pump **25**. A second pressure controlled check valve **31** is similarly disposed along the second line **29** before the lower cylinder section **24**. A crossover pressure control line **32** connects the first valve **30** to the second line **29** for pressure actuation, and a second crossover pressure control line **33** is similarly connected between the second valve **31** and the first line **28**. The pressure controlled check valves **30** and **31** normally permit flow only into the cylinder **20**. When the pressure from a crossover pressure control line **32** and **33** reaches a pre-determined limit, the corresponding pressure controlled valve **30** or **31** automatically opens to enable fluid flow in either direction.

7.3.3. Cylinder Mounting

Deciding the form of mounting to be used with a cylinder involves a consideration of the type of operation to be carried out and the nature of the load. Standard cylinders are not designed to absorb piston rod side loading and thus need mounting in such a way that the

load moves precisely parallel to and in alignment with the actuator centreline. Where the load follows a straight line path with little or no deviation, a rigid mount such as end flange or foot mounting can be used. This is not the case with our design. In the case of raising and lowering the frame, where the load turns in one plane then a clevis or trunnion mounting might be appropriate. These allow the actuator to swivel around the mount as the direction of the load changes. Looking at the types of mounts below, a rear hinged mounting will be most suitable for the design, and this will be installed on either side of the grizzly, below the I-beams, where they are away from any type of damage as a result of coal dumps.

7.4. Reliability

Reliability is a term that is used to describe the chance of a given component will perform to its required specifications within a certain environment at any point in time. This tool is used in many areas of engineering to help in predicting the feasibility and life of a given component within a system. The reliability and effectiveness of a component is found by calculating the probability that a component will perform its function adequately over a given life (MEC3303 2006). The reliability of a given system can be determined in a number of ways depending on the scope of the system. The reliability of the physical components encompassing the Main Frame system can be determined using the reliabilities of each individual part and component in the system. This particular design would most likely be considered a multi-stage system as some components and sub-systems run in parallel to each other, although most of the design uses a step-by-step series system approach.

In the case of the Main Frame design system, the reliability of the individual components within the overall design is not considered in this thesis. This is due to a lack of relevant knowledge on the probabilities of failure for each component in the system. This means that the reliability rates of these components would be very rough estimates without any specific testing and analysis performed.

Another way to analyse the reliability of a system is through the testing and analysis of the failures of completed products over a period of time. This form of product study uses a Weibull distribution of failure to determine the reliability, unreliability and rate of failure for a given system. Weibull analysis samples a range of products in service to find the approximate ratio of failure and time for that product.

The reliability of the Main Frame design is determined through the calculated reliability and failure rate of clearing the grizzly from the lumps of coal that are caught on it. This value of "clearance" would then be compared to MPS's own standards of a clear grizzly, to see if it has met the minimum requirements for clearing the grizzly. A grizzly that remains unclear of coal would be said to have "failed" this test. The effectiveness of the system would be calculated as a percentage of the number of grizzly holes cleared divided by the number of blocked holes to begin with. A Weibull analysis would then help calculate the distribution of failure and reliability of the design.

Reliability analysis cannot be completed until the Main Frame design has been constructed and initial testing and development of the effectiveness of the overall design has begun. Only through the conduction of an experiment on clearing the grizzly can the reliability of the system be accurately found. It is not possible to give a reliability value to a design without experimental data, but an expected result relating to potential reliability and analysis could be roughly estimated.

It is hoped that the Main Frame design efficiently and effectively clears the ROM grizzly, and therefore giving a high reliability that the design performs its specified function ant any given time. This could be achieved through the use of proper length and shaped picks and proper hydraulic forces to lower the frame at a speed that guarantees clearing the grizzly. This would be achieved through a combination of proper positioning of the hydraulic arms along with the right amounts of oil pumped and forces generated. Overall, after thorough discussion with MPS, a potentially low failure output is expected and a high coal clearance coal expected, giving a high reliability for this design.

7.5. Programmable Logic Controllers (PLCs)

PLCs are microprocessor-based controllers that use a programmable memory to store instructions and implement functions such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes. Thus with inputs to the PLC of signals from sensors such as limit switches and start/stop switches, output signals are sent to the solenoid of the valves, the sequence of such signals being determined by the programme of instructions inputted to the PLC.

The PLC is required for several reasons, mainly to control the raising and lowering of the frame, in time, with the trucks dumping the coal. Timing is a very important factor, since the frame would get damaged if any dumping took place with the frame lowered, and on top of that, interrupting the mining process and power generation which would be crucial to MPS.

7.5.1. Mechanical Design of a PLC system

There are two common types of mechanical design: a *single* box and the *rack* type. Single box is generally used for small programmable controllers while the rack type can be used for all sizes of programmable controllers and has the various functional units packaged in individual modules which can be plugged into sockets in a base rack.

Programs are entered into a PLCs memory using a program device which is usually detachable and be moved from one controller to the next without disturbing operations. It is not necessary for the programming device to be connected to the PLC. With MPS, the ideal solution would be the use of personal computers, as program development workstations. This could be in the control station that monitors and controls the rest of the mine and power plant. Some PLCs only require the computer to have appropriate software, others special communication cards.

The PLC program needs to be triggered somehow before the frame simulation could commence. This could be either in the form of automatic remote control sensors, or be triggered manually by coal truck drivers dumping the coal. I would not recommend

manual stimulation of the PLC, since there could be a slight chance that the truck driver could forget, ending up either in time delay of the mining process, or damage to the design from dumping on the frame when in a lowered position.

7.5.2. Photoelectric Sensors

After a telephone conversation with Tony Waller, Technical & Applications Engineer, Sick Pty. Ltd (http://www.sick.com.au), I was advised that the best sensor for my application would be a through beam photoelectric sensor, and that a sensor with a metal housing would be recommended. A photoelectric sensor is a device used to detect the presence of an object by using a light transmitter, often infrared, and a photoelectric receiver. There are three functional types. An opposed arrangement consists of a receiver located within the line-of-sight of the transmitter. In this mode, an object is detected when the light beam is blocked from getting to the receiver from the transmitter. A retro reflective arrangement places the transmitter and receiver at the same location and uses a reflector to bounce the light beam back from the transmitter to the receiver. An object is sensed when the beam is interrupted and fails to reach the receiver. A proximity-sensing arrangement is one in which the transmitted radiation must reflect off of the object in order to reach the receiver. In this mode, an object is detected when the receiver sees the transmitted source rather than when it fails to see it

There are two main types of photoelectric sensors that were advised by Tom, the WS/WE 24-2 and the more powerful WS/WE 45. Previous success has been attained at Stanwell using the WS/WE 45 for monitoring the fill levels of coal bins. The WS/WE 24-2 model has a shorter range of 60m compared to 350m of the 45 model, but is much more economical. The 24-2 model costs $1100, whilst the 45 model costs $2350, both including dust shields. The only problem that could be encountered would be the sensor not detecting the truck. That could be due to the truck reversing beyond the sensors or the gaps in the truck body. This problem could be prevented by mounting the beam at an angle or what I would recommend, the use of two through beams, which would be a little bit more costly but would guarantee not missing the truck in any way. The sensors would

be mounted on the sides of the shed. Detailed information regarding the sensors are found in Appendix J.

7.6. Control Process

As the truck reverses into the grizzly to dump the coal, it is sensed by two photoelectric sensors, which are mounted to the sides of the shed, which detect its presence. A PLC system is connected to the sensors, and requires two signals before it can activate the hydraulic system. The first signal is received when the truck cuts the beam as it reverses into the grizzly. After the truck has done dumping the coal, it drives off and the sensors connect again, sending another signal to the PLC system. This starts an automatic safety timer of one minute, which should be sufficient time for the truck to be well away. The PLC system then sends a signal to the crossover pressure control line activating it, and so, the corresponding pressure controlled valve automatically opens to enable fluid flow in the negative direction. As a result, the pressurised hydraulic fluid acts over the piston within the cylinder.

The cylinder retracts at a speed of 0.45 m/s (estimated time of 10 seconds for frame lowering), and so, the frame is lowered. As it does so, it pivots about the hinge, through a 90 degree angle range. The hydraulic cylinders also pivot about both ends. At the top the cap is horizontal facing the frame where it is welded, and as the cylinder retracts its angle changes until it becomes vertical when the frame is in its full horizontal position. As the frame comes down, the picks come in contact with the lumps of coal and punch holes right through them, breaking them into smaller pieces, making them fall through the grizzly holes. When the frame reaches a full horizontal position, the PLC system starts a 10 second counter before it starts reversing the process. After the ten second period, the PLC sends signals to the crossover pressure control line activating it, and so the corresponding pressure controlled valve automatically opens to enable flow in the opposite direction. This makes the cylinder expand and push the main frame structure up to its vertical position in 20 seconds, at a speed of 0.225 m/s.

7.7. Safety Mechanism

The receiving hopper is the area that connects the mine to the power station. Therefore, continuous supply of coal from the mine is required for the efficient running of the plant. MPS can therefore not afford any risk of a temporary blockage of the grizzly. It is the responsibility of the operators in the control room to monitor the condition of the grizzly. This can be done by installing a video camera in the ROM area. As such, for smooth operation of the mine, an alarm system needs to be installed in the design, through the PLC system. The alarm is triggered when the main frame is jammed in its lower position. This would only be the case if and when the frame is in any constant position for more than thirty seconds. The alarm will sound or go off, thereby, notifying the operators in the control room, who will then make contact with the truck drivers to stop any dumping. The frame is not designed to handle any extra tonnage and any dumping of coal on a lowered frame will result in blocking the grizzly completely.   This is because when the frame is in a lowered position (with coal collecting on the top) there is no space for the coal to flow. If this were to occur, a whole team of workers would need to be assembled to remove the coal from the frame.

8. Project Cost Analysis

8.1. Cost Engineering

Cost engineering is defined as "the application of scientific and engineering principles and techniques to problems of cost estimation; cost control, business planning and management science" (Humphreys & Wellman 1996).

The first question an engineering manager would ask regarding a proposed design solution is, "How much is the design costing me?" Cost is therefore a major factor in determining the success of any engineering design. A design that is practical but costly would not be considered by MPS. The simpler the design and the smaller the number of operating parts, the less the overall cost. This is because installation and maintenance costs would be minimised overall.

8.2. Preliminary Capital Cost Estimating

Initial cost studies require some basic background knowledge in order to avoid a misleading decision. The information that should be available, prior to beginning such a study, includes the following:

1. Type, quantity and quality of products.
2. Approximate utility requirements, services, and storage and handling requirements.
3. Preliminary flow sheets and plot plans, with varying degrees of information:
    a. Equipment type, size and materials of construction
    b. Building space requirements
4. Possible site location, site conditions, and availability of roads and utilities.

8.2.1. Equipment Pricing

The cost of the equipment can be obtained from firm bids and quotations or previous project equipment costs. With basic design data on hand, the specifications for the equipment can be prepared. These specifications can be submitted to vendors for quotations. Previous project equipment costs maybe available in the MPS database, and

the use of such data has the advantage of maintaining MPS's confidentiality, which could be lost otherwise when quotations are solicited.

8.2.2. Equipment Installation Costs

The installed cost of the equipment includes the cost of purchasing the equipment, transporting it to site, installing it and providing the foundations for it including electrical connections.

8.3. Estimating Operating and Maintenance Costs

To perform an operating cost estimate properly, all costs must be considered in certain specific categories. This is because they are treated differently for purposes of calculating taxes and profitability. When performing the operating cost estimate, good judgement is necessary to avoid excessive attention to minor items which, even if severely over or underestimated, will not have a significant effect on the overall estimate. For our design the main operating costs are the supervision and maintenance costs. The costs of supervision can be roughly estimated by taking a fixed percentage of direct labour costs based upon MPS's experience. Maintenance labour costs are a main determining overall cost. Reliable data on maintenance costs are generally not available. Maintenance costs are often estimated as fixed percentages of depreciable capital investment per year. In MPS's case (being considered a complex plant), this factor could be 10% or higher. Maintenance generally increases with the age of the equipment, although most estimates would use an average figure.

8.4. Cost Budget

Table 5, below, is a document that shows potential cost estimates of the proposed design. It is based on rough estimates of the average market prices of the items. There are five main cost items that are included in the budget. Each item will be discussed in detail for purposes of demonstrating an understanding to MPS of anticipated project costs.

LOCATION:	Millmerran Power Station ROM Grizzly	PROJECT STATUS:	Design Phase
		PREPARED BY:	Ahmed El Komy

1 MATERIAL COSTS

Frame fabrication	$30,000.00
Hydraulics	$30,000.00
Sensors	$2,350.00
Sub total	$62,350.00

2 LABOUR COSTS

Boiler Makers (x2)	$2,400.00
Supervisor	$1,500.00
Sub total	$3,900.00

3 TRANSPORTATION COSTS

Sub total	$1,000.00

4 INSTALLATION COSTS

Hydraulics	$2,000.00
Electrical Wiring	$7,000.00
Crane	$10,000.00
Structure Install	$13,000.00
Sub total	$32,000.00

5 COMMISSIONING COSTS

Consultant Engineer	$10,000.00
Sub total	$10,000.00

TOTAL COSTS	$109,250.00

Table 5 Project Cost Analysis

A main factor to consider is who would be available to set-up the design over the weekend. Recall that no dumping takes place on a weekend. Therefore, this is usually the only time when the ROM is available for service, without having to interrupt the mining process during the other days of the week. This means that the prices will be weekend competitive. Another consideration is that the design needs to be completed during that 24-hr period. Therefore, a crew of dedicated members need to be available for that task. Speaking to David (Engineering Manager, MPS) a budget of $200,000 is available. This is almost double the forecasted budget shown earlier. This is good news, since it means that an extra budget is available for any unforeseen events.

8.4.1. Material Costs

These include the price of the steel, hydraulics, sensors and the hiring of the cranes. If we were to assume an average of $200 per meter for a steel section, that makes the steel a total of $30,000. This price includes the fabrication of the steel section into its desired shape, and includes all the welding as well. A hydraulic pack includes the hydraulic pistons and cylinders, oil pumps, oil reservoir, electric motor and hydraulic hoses. Since a long cylinder is required to lift 9 ton, a hydraulic pack would need to be custom made and $30,000 should cover that cost. The sensors are ready made and need to only be installed. They are at a retail price of $2,350.

8.4.2. Labour Costs

Two boiler makers would be required to be on site for the entire duration of the installation. They are required to perform all the welding and setting up of the design. If we assume $50 per hour rate, two boil makers would cost roughly $2,400 over duration of 24 hours. Any operation on site also requires a supervisor to be attendant for the entire duration of the project. He is required to keep the project on schedule, within a budget, and reports directly to the project engineer. At $60 per hour, the supervisor would cost $1500 for the 2 day period.

8.4.3. Transportation Costs

The steel can not be made on site, since there would not be available labour to perform that task on site. This is because most the labour at MPS are involved in the maintenance side of the MPS operations. This means the steel would need to be fabricated at the nearest workshop and then transported on site. The hydraulics, sensors, and all the off-shelf items would need to be transported onto site, and an average estimated amount of $1000 should cover that cost.

8.4.4. Installation Costs

After the materials have been brought to site and a team assembled, the parts need to be fitted together and installed. Generally, every company that you buy the product from, are expected to install it. The steel frame would be installed by the boil makers. The frame is expected to be welded to the hinges which are welded and bolted to the base for support, and the picks to be bolted to the frame at a cost of $13,000. This also includes the mounting of the sensors to the sides of the shed, since that is relatively the simplest process.

The hydraulics would be installed by the company that set up the design. So the company that custom made the hydraulic system to suit the design would bring a team of people to install them at a cost of $2000 for the entire installation. The electrical wiring needs to be installed and that would cost an extra $7,000. Two cranes are required to be on site during the installation. The first is required to hold the frame and the other is used by the boil makers. It is essential to maintain high safety standards in the workplace. An average crane costs $200 per hour to hire, which is required to operate for a whole 24 hour period (weekend), and since two are required this produces a total cost of $9,600, rounded up to $10,000.

8.4.5. Commissioning Costs

This involves the costs that are necessary to get the design all set-up and working. To do this, a qualified registered staff member, namely a consultant engineer needs to be available to sign off the final product. This is very important for MPS, since it is the consultant that is

accountable for any damages as a result of faulty operation of the design. Also, all safety inspections are under his belt. The consultant would be a qualified engineer with experience in that field. An estimated cost of $10,000 would be needed to sign off the design and get it operational.

8.4.6 Conclusion

Cost analysis, although presented rather simply in this section, is a complex task. The costs calculated in this section represent rough estimates at the very early stages of the project, namely, the research and development phase. In this cost analysis, I have broken down the work into manageable divisions and sub-divisions as appropriate to the construction and design of my project. It is based on limited information available to me. However, it follows that the next step would be to obtain quotes and bids for the various items and components of the project. This will provide a more accurate capital cost estimate. The aim is to reduce the variance between the estimated costs and actual costs while, at the same time, staying either within or under budget. This would only be achieved by further analysis as more information comes to hand.

9. Conclusion

Millmerran Power Station (MPS) is an energy efficient, low cost producer of electricity located in southern Queensland. It supplies approximately 1.1 million homes and sells all of its electricity into the National Electricity Market (NEM). As a coal fired operation, MPS is wholly reliant on a consistent fuel supply of coal from the adjacent coal mine. Any interruption to the supply of coal to the power station has the potential of lowering the operating efficiency and electricity production capacity of MPS.

At the mine, a coal hopper with grizzly (grid) is used for the primary collection and crushing of the run of mine (ROM) coal prior to overland conveyor transportation to the adjacent power plant. The grizzly in the hopper is prone to coal blockages which, (1) interrupt the flow of coal to the primary crusher, and (2) impinge on the effective and efficient running of the operation. The objectives of this project were to research the problem and to develop a safe and cost effective engineering design solution.

This investigation aimed to identify ways of clearing the receiving hopper from any blockage, and to provide a greater understanding of the coal handling system for the maximisation of a safe and smooth operation of the mine, at a low cost. Four major design criteria were considered, (1) ease of construction and installation, (2) functionality and effectiveness, (3) ease of operation and maintenance, and (4) costs. This study used Sketch-Up program to produce conceptual designs for clearing the grizzly. The best design, in terms of meeting the specified criteria, was analysed, detailed and recommended to MPS.

A review of the industry background and relevant literature illustrated that the type of mining practised by MPS results in the collection of large lumps of coal. These lumps of coal finish up being caught in the ROM grizzly, which acts as a sieve/filter protecting the crusher beneath it. The lumps pile up and accumulate until they block the grizzly. This, in turn, disrupts coal supply to the power station potentially reducing power generation.

MPS have developed previously several solutions to the problem, including the use of front end loaders and excavators, which have shown clearly to be inefficient. Therefore, an

automatic system that is cost effective and does not increase any safety risks is highly desirable. In this research project, several designs were produced with the objective of clearing the receiving hopper. The design that was most suitable for the MPS site was further analysed and detailed.

The selected design is a main frame that is both structurally and operationally suited to fit MPS. It involves a rectangular steel frame with rectangular end picks bolted to it. The frame is welded at its base to two hinges to allow for a swing motion. The raising and lowering of the frame is controlled by two hydraulic cylinders welded to either end of the structure. It has been tested theoretically in a laboratory experiment against the actual strength of coal. Continuous checks with MPS management staff, during site visits, allowed for additional refining of the model until it received initial approval.

Timing of the frame cycle is very important between the truck dumps, and so a programmable logic controller (PLC) system was incorporated into the design to regulate the raising and lowering of the frame. In case the frame jams half-way or worse even, at its horizontal level, an installed alarm system would alert the operators in the control room - who have a visual connection with the ROM area via a video camera. These operators would notify the truck drivers to pause until the problem is solved.

The findings of this study provide an increased understanding of coal blockage removal techniques, along with a general awareness of problems in the coal mining industry. This should lead to a design that is more reliable, safer and cheaper to maintain in the long term. As described below, research opportunities still exist to further optimise and improve the design that is being proposed for MPS.

9.1. Limitations of the study

The simplification of the analyses utilised in this investigation has illuminated important characteristics. For example, the forces required to crush the coal, stresses on the frame, length and size of the hydraulic hoses. Several design assumptions needed to be made in order to determine the size of the pin and the design of the hydraulic circuit. With the finite

element analysis, several assumptions were made to make the analysis convenient. Those included, taking only half the model as it is symmetrical, applying loads on the tips at the end of the frame only, and not including the hinge or the hydraulic cylinders in the analysis. However, performing otherwise would have made the analysis very complicated.

Determining the force distribution on the picks is a very complex task as this would depend mainly on the distribution of the coal lumps at the instant. That is why the furthest picks only were taken into consideration. Ascertaining how much force would be required to break the coal was also a major limitation. For instance, several samples of coal from the mine were required to be taken to a lab, cut into exact dimensions, and then have a deformation test applied to them. I applied a theoretical approach with what the university could offer. It was not possible for me to obtain samples from the mine because access to the mine is restricted to authorised persons which complicated the issue for me. Project cost analysis was also another limitation because, at this stage of the research, I was not able to obtain necessary quotes from companies that specialised in every field required for the design.

9.2. Directions for future research

Future investigation into improving the main frame design in order to clear the grizzly should consider applying strategies that will reduce or eliminate the limitations of this investigation, as outlined above. This is very important in future research for MPS, and for other companies that are exposed to the same problem. Primarily, future research should aim to avoid any inappropriate assumptions made during this investigation as exemplified by the over-simplified representation offered in the Sketch-Up models. More detailed engineering drawings would be required, including welding calculations, if the design is to be built and installed properly.

Overall, my selected design proposal won initial approval from MPS management. The next step would be to speak to relevant parts manufacturers and suppliers to obtain estimates of costs and availability of parts. For instance, the hydraulic system needs to be custom made; therefore, the hydraulics manufacturing company would need specific information. For example, weight of the structure that requires lifting, length and size of required hoses,

before the hydraulic pack can be designed. Once all the parts are identified and resourced by the suppliers, the next step would be to determine availability of labour for the required installation period. In particular, establish firmly the feasibility of the project being completed within 48 hours over a weekend. Finally, the design would need to be tested before it could be commissioned.

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Appendix A – Project Specification

Project Specification 2007

Student:	Ahmed El Komy
Student No.:	0050047382
Supervisor:	R. Fulcher
Sponsor:	Millmerran Power Station
Industry Advisor:	David Hunt, Engineering Manager.
Title:	Millmerran Power Station ROM Coal Blockage Removal System
Aim:	Design of a system to clear ROM grizzly for coal blockages.

Objectives:

9. Define and describe current Millmerran Power Station (MPS) coal handling system including the mine and the operation of the power station.

10. To undertake a literature review of bulk materials handling, including conveyor design, crusher systems and problems in coal mining industry.

11. Identify significant problems with the current MPS ROM grizzly system.

12. Propose engineering solutions to the identified problems in MPS ROM grizzly system.

13. Conduct a cost benefit analysis of the suggested solutions.

14. Formally report the findings to the project sponsor.

15. Write a dissertation of the project work.

If time permits

16. Report on any implemented solutions.

Student: A El Komy   **Signature:**   **Date:**

Supervisor: R Fulcher   **Signature:**   **Date:**

Appendix B – Project Timeline

Task	March	April	May	June	July	August	September	October
Topic Allocation	14/03/2007							
MPS Site Visit	19/03/2007							
Project Specification	26/03/2007							
General Project Layout								
Coal and its uses								
The Coal industry								
Power Plant review								
Feasibility Study								
Conceptual Designs								
Presentation			19/05/2007					
Project Appreciation			21/05/2007					
MPS Site Visit								
Final Design Layout								
Components of Design								
Modelling Design								
Calculations								
Final Presentation								
MPS Site Visit								
Project Write -up								
Submission								

B.2

Appendix C – General Calculations

Cleaning Mechanism:

Simon advised there are roughly 9 loads every 1hr.

This means 9 loads every 60min.

Therefore, $\dfrac{60}{9} = 6.667$, which is 6 min and 40sec

Rounding up this is approximately 1 load every 7 minutes.

Previously, cleaning took place using a **992 Front End Loader**.

Cleaning used to take 20min per hour, i.e. 20min per 9 loads.

This is roughly 2.5 minutes of cleaning time per load.

Now, cleaning takes place using a **20T Excavator**. It is used 5 times in one day. That is 5 times in 12 hours, hence 5 times per 108 loads.

Therefore, the 20T excavator would be used once every $\dfrac{108}{5} = 22 loads$

Weight of main frame:

Parallel Flange channel weighs 55.2kg/m (Appendix I)

8 Vertical Columns x 7.4m x 55.2 = 3267.84 kg
2 Vertical Columns x 8.0m x 55.2 = 883.2 kg
7 Horizontal Columns x 12.4 x 55.2 = 4791.36 kg
Total weight of system = 3267.84 + 883.2 + 4791.36 = 8942.4 kg

Therefore, the frame weighs around 9 tons.

Appendix D – Pin Calculations
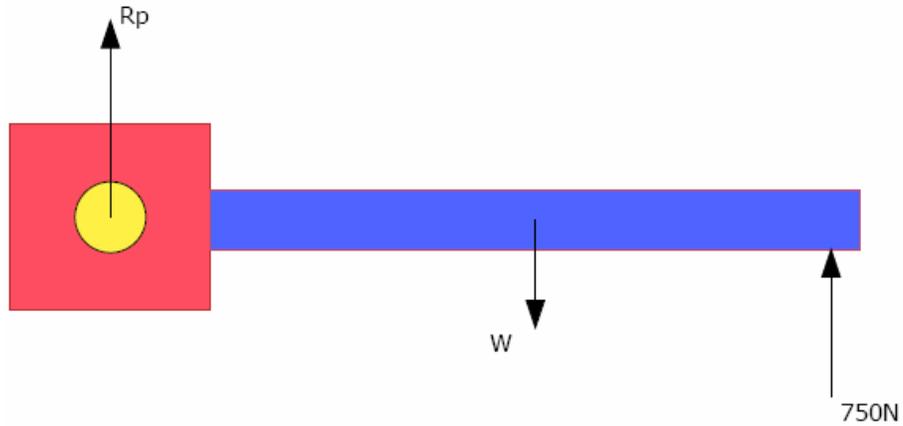
The beam is assumed to be a cantilever beam hinged at one end a free load is applied at the other end.

Need to calculate a suitable value for the hinge pin.

Assumptions: Data shear strength of pin material $= 1.5 \ MN/m^2$

Factor of Safety (FOS) $= 5$

Determine the weight of the beam:

From material properties, Appendix I the beam weighs 55.2kg/m and measures 8036mm in length. The total mass is therefore:

$$m = 55.2x8.036 = 443.6kg$$
$$w = mg = 443.6x9.812 = 4352.5N$$

Determine reaction forces at the Pin:

$$\sum Fy = 0$$

$$Rp + 750 - w = 0$$
$$Rp = 3602.5N$$

State the maximum working shear stress in the Pin:

D.2

Allowable shear stress in Pin $= \dfrac{1.5}{5} = 0.3 MN/m^2$

Pin is in double shear, therefore $\tau_{all} = 2 \times 0.3 = 0.6 MN/m^2$

$\tau_{pin} = \dfrac{Force}{CA_{pin}}$; where CA = Cross-Sectional Area

Re-arrange the equation to find CA_{pin}

$$CA_{pin} = \dfrac{Force}{\tau_{pin}} = \dfrac{3602.5N}{0.6 x 10^6 \, N/m^2} = 6.004 x 10^{-3} m^2$$

Area of Pin, $A = \dfrac{\pi}{4} d^2$;

Re-arrange the equation to calculate the diameter of the pin:

$$d = \sqrt{\dfrac{4A}{\pi}} = \sqrt{\dfrac{4 x 6.004 x 10^{-3}}{\pi}} = 0.0874 m$$

This figure could be rounded up to 0.1m, and hence, a 100mm diameter pin would be sufficient to support the frame structure and withstand the free end load on the tip of the frame.

Appendix E – Matlab Code to calculate beam stiffness & deflection

```matlab
%Script for FINAL YEAR PROJECT
%MILLMERRAN POWER STATION ROM COAL BLOCKAGE REMOVAL SYSTEM
%THIS PROGRAM CALCULATES DEFLECTION, STIFFNESS OF CANTILEVER
%BEAM WITH LOAD W AT FREE END ,
%THE STRAIN ENERGY APPROACH IS USED TO CALCULATE THE DEFLECTION
AND STIFFNESS
%
%The cantilever beam which is fixed at one end and load w at free
%end is analysed by using strain energy method to calculate the deflection at free end.
%Length of cantilever is l , width is B, thickness at fixed end is d1 and thickness at free end
is d2,  Young's modulus E are the parameters require for design.
%
syms x w ;
%
l=8360;      %Length of cantilever beam
d1=380;      %Fixed end thickness
d2=380;      %free end thickness
E=200e3;   %Young's modulus
B=100;       %Constant width of beam
w=750;       %Load at free end
%
f=(x^2)/((d2+((d1-d2)*(l-x)/l))^3);          % Function of strain energy
u= int(f,x,0,l);                             %Integration for obtaining total strain energy
delta= 2*u*(6*(w^2)/(E*B))/w                 %Equating strain energy to work done and
%                                              finding the deflection
stiffness=  (w/delta);                       %From deflection finding the stiffness of the
%                                              tapered cantilever beam
stiffness1=3*E*B*(d1^3)/(12*l^3)
```

E.2

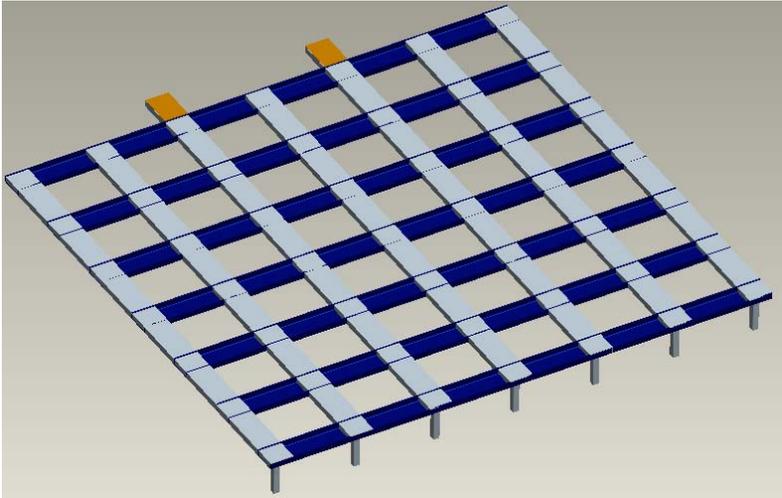# Appendix F – Finite Element Analysis Report

FEA Model Report

Job Name: FEA on Frame
Job Number: 1
Analyst: Ahmed El Komy

| **Problem Description:**	**Related Drawings:**
	See attached figures

The figure shown is the main frame which consists of parallel flange channels connected horizontally and vertically forming a rectangular shape. At its intersections, picks of 0.5m length are bolted to them. The picks are designed to break the big coal lumps that end up on the grizzly. They are 100x100 RHS (Rolled Hollow Sections) with square ends, which are sufficient to punch holes and break the lumps of coal.

In this task, I am doing a finite element analysis on the main frame. The frame is supported on both its ends with hydraulic rams that control the rate of the free fall of the frame and raise it back to its original position. It's welded at its base to two hinges that allow it to swing in a 90 degree range. A model of the frame has been produced using ProEngineer Wildfire.

My approach will be to investigate what happens to the frame when it comes in contact with the coal. Newton's third law simply states that for every action there is an equal and opposite reaction. So the force required to break the coal acting downwards would be the same force acting upwards into the picks. The picks are connected to the frame, and therefore this force is likely to affect the steel structure and could result in deflection, and in some cases, if the force is too big, deformation of the beam.

The figure to the right is half the model that was input into ANSYS. Reasons for this set-up will be explained later.
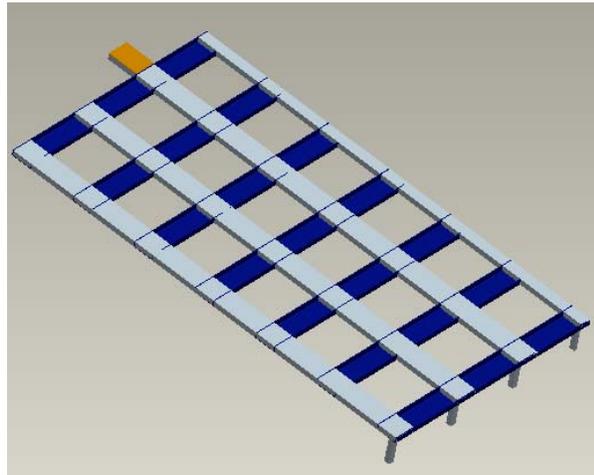
Approach to Analysis

Analysis Type: Static Structural

Package Used: ANSYS 10.0

**Elements Used:** N/A – Set by Wokbench

Modelling Assumptions:

- The whole structure (including the plate, beams and picks) are made of structural steel.
- Uniform distribution of stress, which often results in simple tension/compression or shear, depending on how the external force was applied to the body. Simply meaning, there are no complicating effects. In our case, a surface force F is applied at the end of the picks. The assumption of uniform stress means that if we cut a horizontal section of the pick, we can replace its effect by applying a uniformly distributed force of magnitude σA to the cut end. So that the stress σ is said to be uniformly distributed.
- The picks are assumed to be simply 'connected' to the frame, instead of being bolted to the frame.
- The two plates connected to the bottom of the frame are where the frames are welded to the hinge, but a fixed supported plate has been used for simplification.
- The channel beams are assumed to be cantilever beams with one end fixed and the other under the influence of an external load.
- The structure is exactly symmetrical, and so only HALF of the model was put into ANSYS (reason for that explained in the next section).
- The picks have only been put at the tip of the frame, simply because this would be where the forces would have the biggest influence on the structure since, the further from the hinge, the bigger the moment force exerted.

Basic Model (including mesh generation):

- Model was produced using ProEngineer Wildfire.
- Model was imported into ANSYS workbench, units set to mm, and the model was generated.
- Prepare a new simulation, and view the simulation wizard to not miss out on any steps in the process.
- I identified the material to be structural steel applied to all the parts.
- Fixed supports were applied to the plate, and a frictionless support applied to the side where the model was cut. This enables the frame to sill move in its desired axis.
- I also inserted mesh sizing, where I assumed the critical surface of stress would be

at, at a sizing of 5mm.

- **A surface force of 750N (explained in chapter 7) was applied to the tip of each pick. This represents the force exerted on the picks from crushing the coal lumps on the grizzly.**

- **I started the simulation only to find an error produced saying the matrix is out of bounds and to consider turning large deflection on. The structure would be totally deformed and the last beam would be displaced. So I thought that a contact region could be missing. I expanded the tab in ANSYS only to see that there was no problem there. So I decided to go back to ProEngineer and save the model as IGES. And I knew this would eliminate the problem with contact regions. It simply does that by joining up the whole model making it one part. I ran the simulation again with the same error coming up, so I checked the numbers of nodes to find 248000 nodes were being generated by the mesh. I went back to the mesh sizing to produce less nodes, only to find the same error still generated at 165000 nodes. So I unchecked the sizing and let ANSYS generate it automatically, only to find the same problem.**

- **I decided to go back to ProEngineer and, since the model is symmetrical, to cut it in half, and put that into ANSYS, and I got results. The reason for that was that the number of nodes this time was less that 120 000, and the number of elements was reduced by half. The model was then ready to be simulated by ANSYS.**
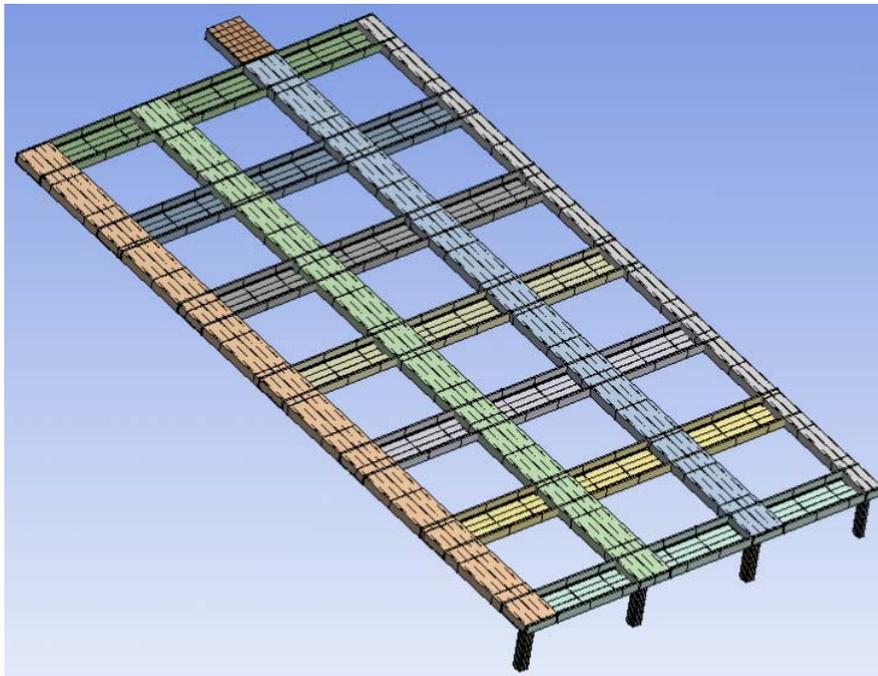
Default Freedom Conditions: UX,UY,UZ

F.5

Results

Bodies:

Name	Material	Nonlinear Material Effects	Bounding Box(m)	Mass (kg)	Volume (m³)	Nodes	Elements
"C_BEAM_VERT[52]"	"Structural Steel"	Yes	0.1, 0.19, 7.76	214.22	2.73×10^{-2}	818	165
"VERT_LONG[55]"	"Structural Steel"	Yes	0.1, 0.38, 8.32	459.14	5.85×10^{-2}	1490	336
"C_BEAM_VERT[60]"	"Structural Steel"	Yes	0.1, 0.38, 7.76	428.44	5.46×10^{-2}	1401	315
"C_BEAM_VERT[63]"	"Structural Steel"	Yes	0.1, 0.38, 7.76	428.44	5.46×10^{-2}	1401	315
"C_BEAM[66]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[76]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[77]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[78]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[79]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[80]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"C_BEAM[81]"	"Structural Steel"	Yes	0.11, 4.18, 0.38	235.12	3.0×10^{-2}	1458	385
"PLATES[93]"	"Structural Steel"	Yes	0.02, 0.38, 0.56	33.11	4.22×10^{-3}	308	35
"PICKS[106]"	"Structural Steel"	Yes	0.6, 0.05, 0.1	23.48	2.99×10^{-3}	589	80
"PICKS[107]"	"Structural Steel"	Yes	0.6, 0.1, 0.1	46.95	5.98×10^{-3}	1589	288
"PICKS[108]"	"Structural Steel"	Yes	0.6, 0.1, 0.1	46.95	5.98×10^{-3}	1589	288
"PICKS[109]"	"Structural Steel"	Yes	0.6, 0.1, 0.1	46.95	5.98×10^{-3}	1589	288

Contact Conditions:

Name	Type	Associated Bodies	Scope	Normal Stiffness	Scope Mode	Behavior	Update Stiffness	Formulation	Thermal Conductance	Pinball Region
"Contact Region"	Bonded	"C_BEAM_VERT[52]" and "C_BEAM[66]"	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 2"	Bonded	"C_BEAM_VERT[52]" and "C_BEAM[76]"	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled

"Contact Region 3"	Bonded	*"C_BEAM_VERT[52]" and "C_BEAM[77]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 4"	Bonded	*"C_BEAM_VERT[52]" and "C_BEAM[78]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 5"	Bonded	*"C_BEAM_VERT[52]" and "C_BEAM[79]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 6"	Bonded	*"C_BEAM_VERT[52]" and "C_BEAM[80]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 7"	Bonded	*"C_BEAM_VERT[52]" and "C_BEAM[81]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 8"	Bonded	*"VERT_LONG[55]" and "C_BEAM[66]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 9"	Bonded	*"VERT_LONG[55]" and "C_BEAM[76]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 10"	Bonded	*"VERT_LONG[55]" and "C_BEAM[77]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 11"	Bonded	*"VERT_LONG[55]" and "C_BEAM[78]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 12"	Bonded	*"VERT_LONG[55]" and "C_BEAM[79]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 13"	Bonded	*"VERT_LONG[55]" and "C_BEA*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled

F.7

		M[80]"							
"Contact Region 14"	Bonded	*"VERT_ LONG[55]" and "C_BEA M[81]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 15"	Bonded	*"VERT_ LONG[55]" and "PLATE S[93]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 16"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[66]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 17"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[76]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 18"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[77]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 19"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[78]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 20"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[79]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 21"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[80]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 22"	Bonded	*"C_BEA M_VER T[60]" and "C_BEA M[81]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 23"	Bonded	*"C_BEA M_VER T[63]" and "C_BEA M[66]"*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed
"Contact Region 24"	Bonded	*"C_BEA M_VER T[63]" and*	Face, Face	Program Controll ed	Automa tic	Symme tric	Never	Pure Penalty	Progra m Controll ed	Progra m Controll ed

F.8

		"C_BEAM[76]"								
"Contact Region 25"	Bonded	*"C_BEAM_VERT[63]" and "C_BEAM[77]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 26"	Bonded	*"C_BEAM_VERT[63]" and "C_BEAM[78]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 27"	Bonded	*"C_BEAM_VERT[63]" and "C_BEAM[79]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 28"	Bonded	*"C_BEAM_VERT[63]" and "C_BEAM[80]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 29"	Bonded	*"C_BEAM_VERT[63]" and "C_BEAM[81]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 30"	Bonded	*"C_BEAM[66]" and "PICKS[106]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 31"	Bonded	*"C_BEAM[66]" and "PICKS[107]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 32"	Bonded	*"C_BEAM[66]" and "PICKS[108]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 33"	Bonded	*"C_BEAM[66]" and "PICKS[109]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled
"Contact Region 34"	Bonded	*"C_BEAM[81]" and "PLATES[93]"*	Face, Face	Program Controlled	Automatic	Symmetric	Never	Pure Penalty	Program Controlled	Program Controlled

Structural Loading:

Name	Type	Magnitude	Vector	Reaction Force	Reaction Force	Reaction Moment	Reaction Moment	Associated

				Vector		Vector	Bodies
"Force"	Surface Force	750.0 N	[-750.0 N x , 0.0 N y,0.0 N z]	N/A	N/A	N/A	N/A	*"PICKS[109]"*

Structural Supports:

Name	Type	Reaction Force	Reaction Force Vector	Reaction Moment	Reaction Moment Vector	Associated Bodies
"Fixed Support"	Fixed Surface	1,650.41 N	[749.98 N x, -1,470.17 N y, 0.23 N z]	3,809.16 N·m	[1,467.86 N·m x, -3,493.76 N·m y, 385.69 N·m z]	*"PLATES[93]"*
"Frictionless Support"	Frictionless Support	1,469.99 N	[9.0×10^{-14} N x, 1,469.99 N y, -9.0×10^{-14} N z]	7,026.01 N·m	[-6,894.93 N·m x, 3.39×10^{-13} N·m y, -1,350.84 N·m z]	*"C_BEAM_VERT[63]"*

Solution:

Solver Type is set to Program Controlled

Weak Springs is set to   Program Controlled

Large Deflection is set to Off

***"Solution"* contains the calculated response for *"Model"* given loading conditions defined in *"Environment"*.**

- **Thermal expansion calculations use a constant reference temperature of 22.0 °C for all bodies in *"Model"*. Theoretically, at a uniform temperature of 22.0 °C no strain results from thermal expansion or contraction.**

Structural Results:

Name	Figure	Scope	Minimum	Maximum	Minimum Occurs On	Maximum Occurs On	Alert Criteria
"Equivalent Stress"	A1.1, A1.2	All Bodies In *"Model"*	10.08 Pa	7.12×10^7 Pa	PICKS[106]	C_BEAM_VERT[60]	None

"Maximum Shear Stress"	A1.3, A1.4	All Bodies In *"Model"*	5.75 Pa	4.11×10^{7} Pa	PICKS[106]	C_BEAM_VERT[60]	None
"Total Deformation"	A1.5, A1.6	All Bodies In *"Model"*	0.0 m	2.0×10^{-2} m	PLATES[93]	C_BEAM_VERT[63]	None

Equivalent Stress Safety:

Name	Scope	Type	Minimum	Alert Criteria
"Stress Tool"	All Bodies In *"Model"*	Safety Factor	3.51	None
"Stress Tool"	All Bodies In *"Model"*	Safety Margin	2.51	None

Shear Stress Safety:

Name	Scope	Type	Minimum	Alert Criteria
"Stress Tool 2"	All Bodies In *"Model"*	Safety Factor	3.04	None
"Stress Tool 2"	All Bodies In *"Model"*	Safety Margin	2.04	None

Results

Equivalent Von Misses Stress
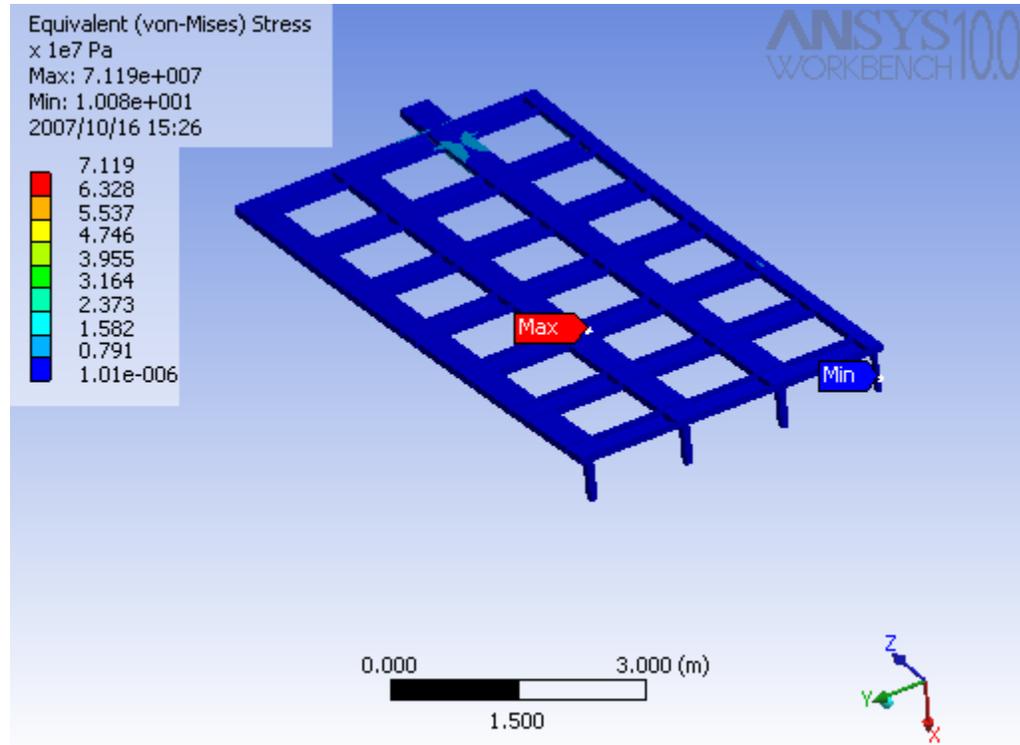
Figure 4
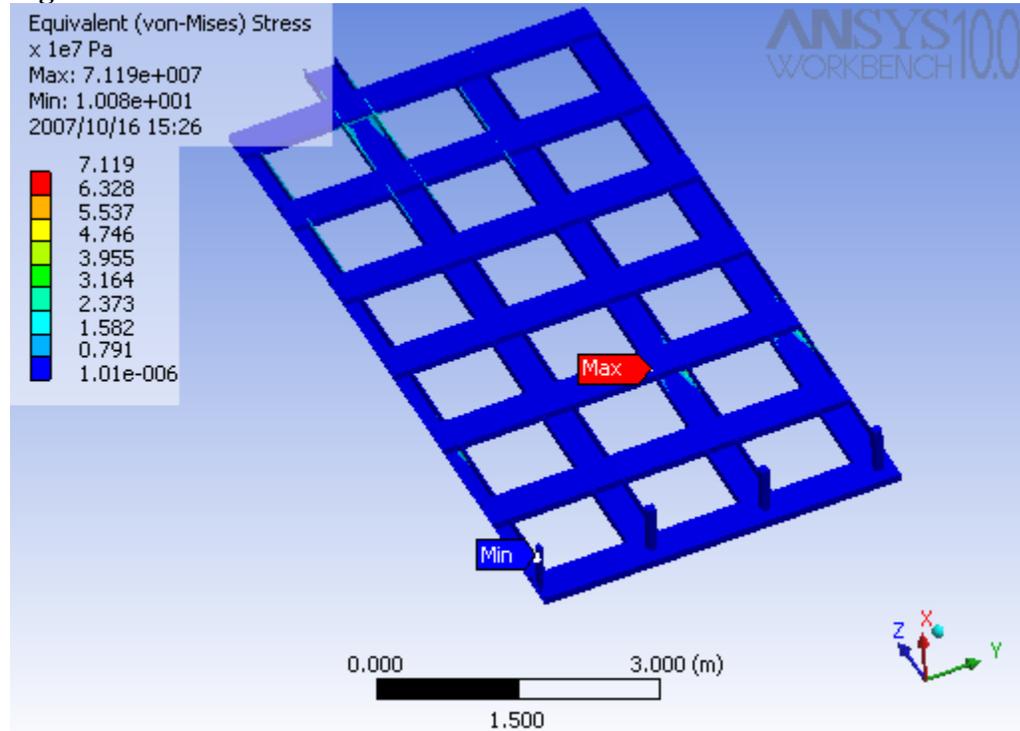
Figure 5   F.12

Maximum Shear Stress

Shear Stress
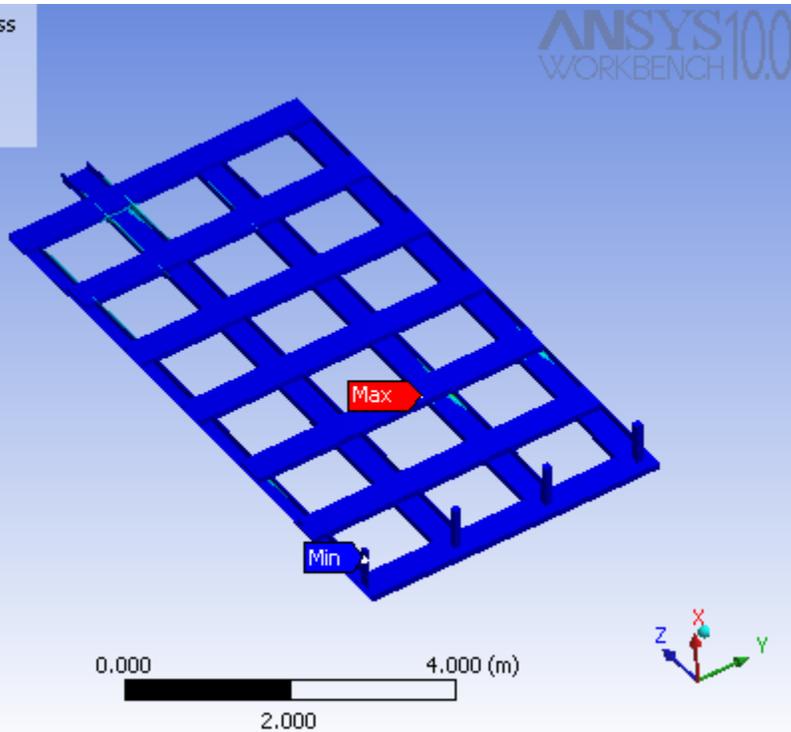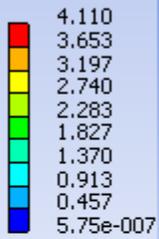
Figure 6

F.13
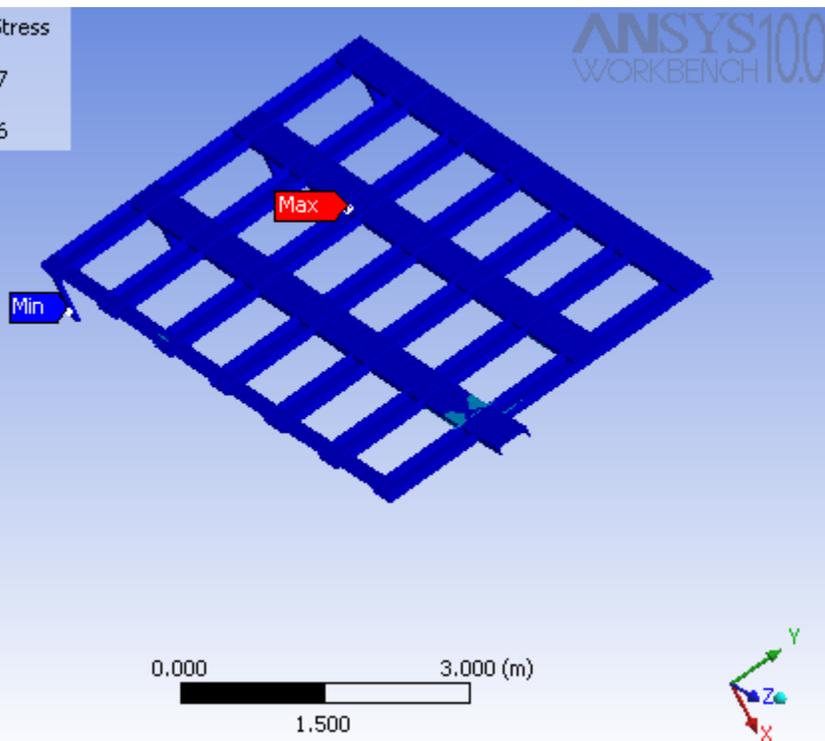
Figure 7
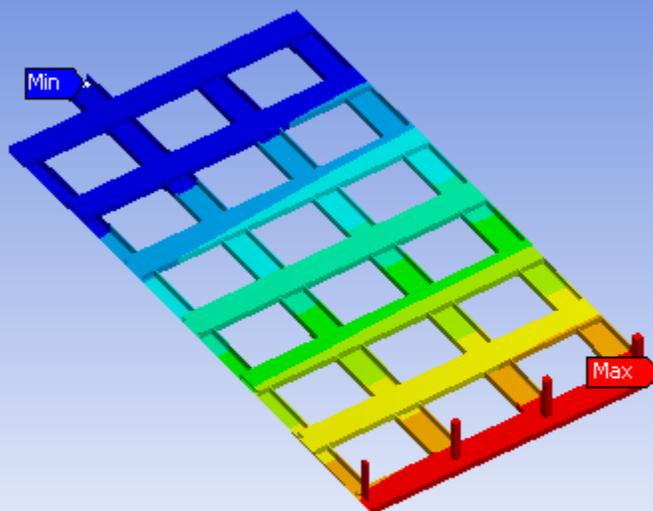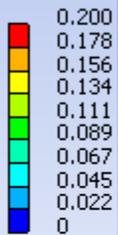
Total Deformation
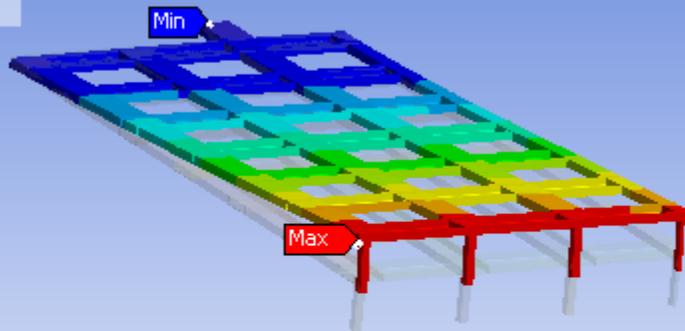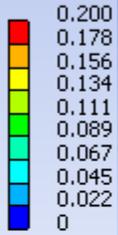
Figure 8

Figure 9

F.14

Discussion of Results:

Recall that the failure criterion based on the maximum distortion energy theory for ductile materials subjected to static loading predicts that a material will fail if the Von Mises stress reaches the yield strength of the material.

Figures 4 and 5 show the equivalent Von-Mises stress distribution. Figures 6 and 7 show the maximum shear distribution. You can see that the maximum stress takes place at the third horizontal beam from the end, at the intersection. The other area on the frame that experienced almost similar effects is the vertical frame connected to the frame. This is obvious since the structure is fixed at that end, whilst the other end is exposed to a free end load. The maximum shearing stress calculated is 41.1 MPa. There was minimal equivalent stress and shearing stress on the picks. The overall structure besides those two locations mentioned, did not experience any form of major stress. So this clearly shows that in the long run of use of the frame, the central region is generally where most the stress would be lying, not the tips like many would think. You can also see that the use of the hydraulic rams on either end would mean more support to the structure on the sides, and hence more stress in the mid-central area. Overall, the structure can withstand the load, since the equivalent Von-Mises stress calculated is 79.9MPa whilst the material yield strength is 250MPa.

Figures 8 and 9 show the total deformation of the structure. The overall maximum displacement of the structure is 0.02003m which is roughly 20mm, and is located where the picks make contact with the frame. This is a reasonable suggestion, since the force is translated from the coal onto the picks, and into the frame, and so is the highest force exerted at the instant and so, experiences the maximum displacement. The minimum displacement is at the support plates, where the supports are strong enough that no deformation takes place.

Action to be taken:

Relate the numbers obtained to manual calculations, and see where and why any differences would be there. The analysis could be enhanced by applying the reaction forces of the hydraulic rams on either end, and also, by having the picks on all the intersections and applying forces to them, this would make the analysis complex with so many different parts, but would produce more accurate results.

Signed:	Date: 21/10/07

F.15

Appendix

Structural Steel Constants Properties

Name	Value
Compressive Ultimate Strength	0.0 Pa
Compressive Yield Strength	2.5×10^8 Pa
Density	7,850.0 kg/m³
Poisson's Ratio	0.3
Tensile Yield Strength	2.5×10^8 Pa
Tensile Ultimate Strength	4.8×10^8 Pa
Young's Modulus	2.0×10^{11} Pa
Thermal Expansion	1.2×10^{-5} 1/°C
Specific Heat	434.0 J/kg·°C
Thermal Conductivity	60.5 W/m·°C
Relative Permeability	10,000.0
Resistivity	1.7×10^{-7} Ohm·m

Alternating Stress Graph

F.16
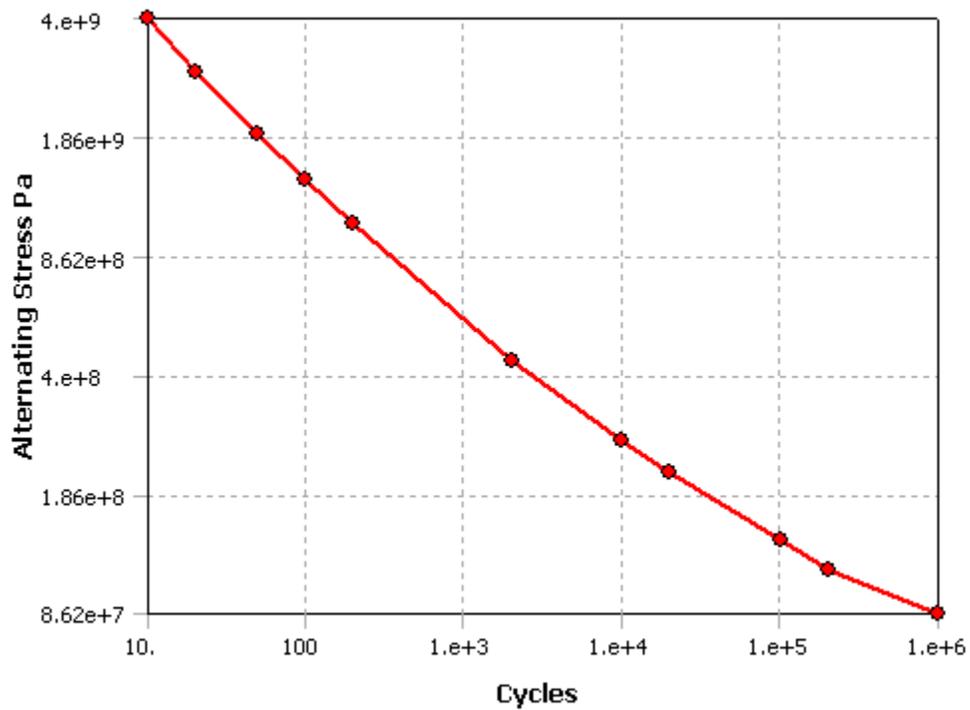
Alternating Stress Table

Cycles	Alternating Stress
10.0	4.0×10^9 Pa
20.0	2.83×10^9 Pa
50.0	1.9×10^9 Pa
100.0	1.41×10^9 Pa
200.0	1.07×10^9 Pa
2,000.0	4.41×10^8 Pa
10,000.0	2.62×10^8 Pa
20,000.0	2.14×10^8 Pa
100,000.0	1.38×10^8 Pa
200,000.0	1.14×10^8 Pa
1,000,000.0	8.62×10^7 Pa

Strain Life Parameters Graph

F.17
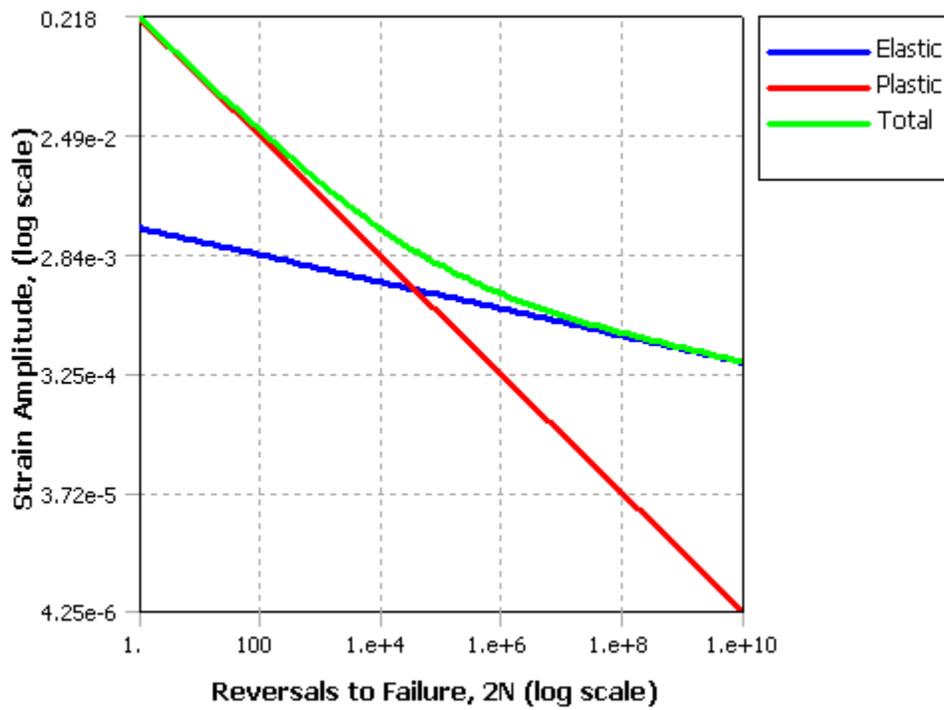
Strain Life Parameters Table

Strength Coefficient	9.2×10^8 Pa
Strength Exponent	-0.11
Ductility Coefficient	0.21
Ductility Exponent	-0.47
Cyclic Strength Coefficient	1.0×10^9 Pa
Cyclic Strain Hardening Exponent	0.2

Appendix G – Hydraulic System Design Calculations

We are required to design a hydraulic system to safely lift a 9000kg mass through a vertical height of 4.5m in estimated time of 20 seconds. Assume a working pressure of 20MPa.

Given data:

Load (approx)   = 90 000 N = 90 KN

Distance travelled   = 4.5m = length of ram = length of forward stroke

Time taken   = 20 seconds

Average speed of travel = distance/time = 0.225m/s

We will begin by determining the dimensions of the hydraulic cylinder (we would assume that the maximum load of 90 KN is moved on the forward stroke).

1. Diameter of piston – internal diameter of cylinder

From

$$\Pr essure = \frac{Force}{Area};$$

$$Area = \frac{Force}{\Pr essure} = \frac{90000}{20x10^6} = 4.5x10^{-3}m^2 = 4500mm^2$$

From

$$Area = \frac{\pi d^2}{4};$$

Diameter $D = \sqrt{\frac{Area x 4}{\pi}} = 75.69mm$

The diameters of hydraulic cylinders are usually supplied in standard sizes available in increments of 5 or 10mm.

Hence, let us choose a piston diameter of 80mm.

2. Diameter of Piston Rod

Assume a modulus of elasticity of 200GPa for the material of the rod, and a safety factor of 2, therefore, (design load = 180 000 N) and an equivalent free length equal to the stroke length (pinned at both ends).

From Euler's Equation:

$$P_{cr} = \frac{\pi^2 EJ}{L_e^2} = \frac{\pi^2 E(\frac{\pi D^4}{64})}{L_e^2} ;$$

Therefore, Rod Diameter $D = \sqrt[4]{\dfrac{64 x L^2 x K}{\pi^3 E}}$

$$= \sqrt[4]{\frac{64 x (4.5)^2 x 180000}{\pi^3 x 200 x 10^9}} = 0.0783m = 78.3mm$$

This figure could be rounded up to 80mm.

3. Flow rate of hydraulic fluid

We first need to determine the volume of the cylinder at full extension.

From Volume = Area x Stroke Length

$$= \frac{\pi (80)^2}{4} x4500 = 22\ 619\ 467.11\ mm^3 = 0.0226\ m^3$$

This could also be 22 619 cm^3 = 22.6 litres

The full stroke of the piston takes 20 seconds. Hence, we would require the full volume of the cylinder every 20 seconds, i.e. a flow rate of 67.8 l/min ($0.678\ m^3 / min$).

This information can then be used to select a cylinder and a pump.

G.3

Appendix H – Millmerran Power Station Engineering Drawings

H.2

H.3

H.4

Appendix I – One Steel Catalogue

Parallel Flange Channels

Table 19 Parallel Flange Channels — Dimensions and Properties

Designation	Mass per metre	Depth of Section d	Flange Width b_f	Flange Thickness t_f	Web Thickness t_w	Root Radius r_1	Depth Between Flanges d_1	$(b_f-t_w)/t_f$	Gross Area of Cross-Section A_g	Coord. of Centroid x_L	Coord. of Shear Centre x_0	I_x	Z_x	S_x	r_x	I_y	Z_{yR}	Z_{yL}	S_y	r_y	Torsion Constant J	Warping Constant I_w	Designation
	kg/m	mm	mm	mm	mm	mm	mm		mm²	mm	mm	10^6mm⁴	10^3mm³	10^3mm³	mm	10^6mm⁴	10^3mm³	10^3mm³	10^3mm³	mm	10^3mm⁴	10^9mm⁶	
380 PFC	55.2	380	100	17.5	10.0	14.0	345	5.14	7030	27.5	56.7	152	798	946	147	6.48	89.4	236	161	30.4	472	151	380 PFC
300 PFC	40.1	300	90	16.0	8.0	14.0	268	5.13	5110	27.2	56.1	72.4	483	564	119	4.04	64.4	148	117	28.1	290	58.2	300 PFC
250 PFC	35.5	250	90	15.0	8.0	12.0	220	5.47	4520	28.6	58.5	45.1	361	421	99.9	3.64	59.3	127	107	28.4	238	35.9	250 PFC
230 PFC	25.1	230	75	12.0	6.5	12.0	206	5.71	3200	22.6	46.7	26.8	233	271	91.4	1.76	33.6	77.8	61.0	23.5	106	15.0	230 PFC
200 PFC	22.9	200	75	12.0	6.0	12.0	176	5.75	2920	24.4	50.5	19.1	191	221	80.9	1.65	32.7	67.8	58.9	23.8	101	10.6	200 PFC
180 PFC	20.9	180	75	11.0	6.0	12.0	158	6.27	2660	24.5	50.3	14.1	157	182	72.9	1.51	29.9	61.5	53.8	23.8	81.4	7.82	180 PFC
150 PFC	17.7	150	75	9.5	6.0	10.0	131	7.26	2250	24.9	51.0	8.34	111	129	60.8	1.29	25.7	51.6	46.0	23.9	54.9	4.59	150 PFC
125 PFC	11.9	125	65	7.5	4.7	8.0	110	8.04	1520	21.8	45.0	3.97	63.5	73.0	51.1	0.658	15.2	30.2	27.2	20.8	23.1	1.64	125 PFC
100 PFC	8.33	100	50	6.7	4.2	8.0	86.6	6.84	1060	16.7	33.9	1.74	34.7	40.3	40.4	0.267	8.01	16.0	14.4	15.9	13.2	0.424	100 PFC
75 PFC	5.92	75	40	6.1	3.8	8.0	62.8	5.94	754	13.7	27.2	0.683	18.2	21.4	30.1	0.120	4.56	8.71	8.20	12.6	8.13	0.106	75 PFC

Table 20 Parallel Flange Channels — Properties for Assessing Section Capacity

Designation	Yield Stress Flange f_y	Yield Stress Web f_y	Form Factor k_f	About x-axis Z_{ex}	About y-axis Load A Z_{ey}	About y-axis Load B Z_{ey}	Designation
	MPa	MPa		10^3mm³	10^3mm³	10^3mm³	
	300PLUS*						
380 PFC	280	320	1.00	946	115	134	380 PFC
300 PFC	300	320	1.00	564	82.3	96.6	300 PFC
250 PFC	300	320	1.00	421	88.7	89.0	250 PFC
230 PFC	300	320	1.00	271	45.1	50.4	230 PFC
200 PFC	300	320	1.00	221	46.7	49.1	200 PFC
180 PFC	300	320	1.00	182	44.9	44.8	180 PFC
150 PFC	320	320	1.00	129	38.5	38.5	150 PFC
125 PFC	320	320	1.00	72.8	22.8	22.8	125 PFC
100 PFC	320	320	1.00	40.3	12.0	12.0	100 PFC
75 PFC	320	320	1.00	21.4	6.84	6.84	75 PFC
	AS/NZS 3679.1-350						
380 PFC	340	360	1.00	946	104	134	380 PFC
300 PFC	340	360	1.00	564	77.2	96.6	300 PFC
250 PFC	340	360	1.00	421	84.9	89.0	250 PFC
230 PFC	340	360	1.00	271	42.6	50.4	230 PFC
200 PFC	340	360	1.00	221	44.5	49.1	200 PFC
180 PFC	340	360	1.00	182	44.1	44.8	180 PFC
150 PFC	360	360	1.00	129	38.5	38.5	150 PFC
125 PFC	360	360	1.00	72.0	22.5	22.8	125 PFC
100 PFC	360	360	1.00	40.3	12.0	12.0	100 PFC
75 PFC	360	360	1.00	21.4	6.84	6.84	75 PFC

I. 2
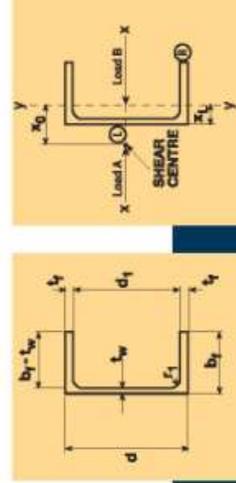
Appendix J – Remote Control Sensors

W 45: Farther than the eye can see

The W 45 with its sturdy metal housing was designed to cope with the most hostile operating environments. The sensors are completely immune to scaling film in steel plants and rolling mills, just as they are to temperatures above 120 °C.

Their efficiency can be increased further with a comprehensive range of accessories such as cooling plates for water cooling, weather hoods and dust shields.

Only photoelectric switches with high performance reserves are suitable for use in hostile operating conditions. The W 45 series has been specially developed for such applications and meets this requirement with ease. The WS/WE 45 through-beam photoelectric switch, which has been tried and tested in industrial environments, has a scanning range of 300 m.

The WL 45 photoelectric reflex switch is incredibly "far-sighted" with a huge scanning range of 45 metres. If a photoelectric proximity switch is required, the WT 45 with its adjustable scanning distance ranging up to 2,000 mm, and background suppression, is ideal even for harsh conditions.

However, it is not only robustness but also the variety of practical design features that characterise this outstanding series of photoelectric switches. To improve "operator-friendliness", the adjusting elements for time delay and sensitivity are housed in an easily accessible terminal chamber. A signal strength indicator together with an integrated optical finder assist alignment of through-beam photoelectric switches – a particularly important consideration bearing in mind the large scanning ranges.

Universal voltage versions and a large range of mounting accessories complete the functionality of the W 45. All UC devices have UL approval for Canada and the USA.
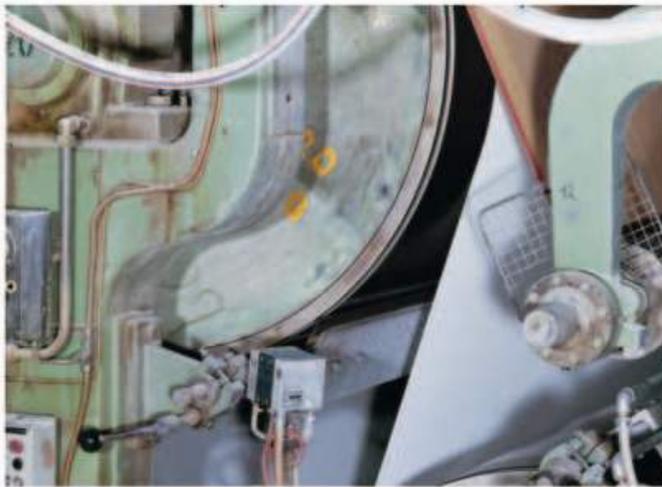
◄ The robust design and large scanning distance are of advantage to the WT 45 photoelectric proximity switch when used to check for tear-off on a paper rolling machine.

► A WS/WE 45 through-beam photoelectric switch monitors tear-off on a paper web.

▲ Extreme operating conditions exist in steel making plants – the WT 45 photoelectric proximity switch is ideal for many applications, such as detecting metal sheets before they are wound onto coils.

► Scale, steam and heat in a rolling mill does not affect the WT 45 – here used to detect the presence of steel slabs.

J. 3

Scanning range 350 m

Through-beam photoelectric switches

- Robust metal housing
- Red light
- Adjustable sensitivity
- Front lens heating, optional
- Pre-failure signalling output

CE ⏚

Dimensional drawing
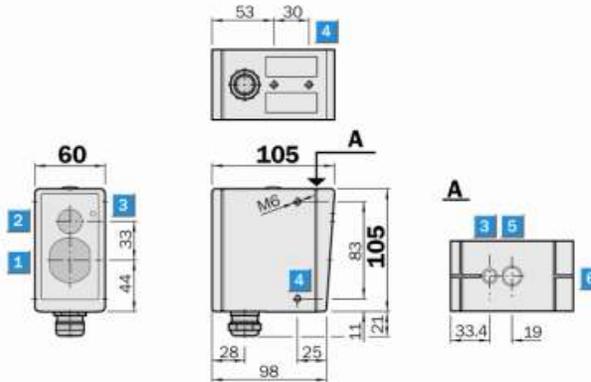
Adjustments possible

WS/WE 45-P 250
WS/WE 45-P 260
WS/WE 45-N 250
WS/WE 45-N 260
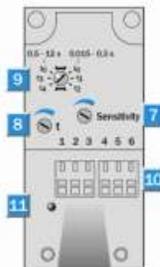
1 Centre of optical axis, sender (WS)
Centre of optical axis, receiver (WE)
2 View finder lens
3 LED signal strength indicator
4 M6 threaded mounting hole – 8 mm deep
5 Eyepiece for alignment aid
6 Alignment sight
7 Sensitivity adjustment
8 Time adjustment
9 Time delay selector switch
10 Terminal strip
11 Status indicator

Switch-selectable time delay

0.5 – 12 s	0.015 – 0.3 s
t_0 without time delay	t_0 without time delay
t_3 ON-delay when object enters detection zone	t_1 ON-delay when object enters detection zone
t_4 OFF-delay when object leaves detection zone	t_2 OFF-delay when object leaves detection zone

Connection type

WS/WE 45-P 250
WS/WE 45-P 260
WS/WE 45-N 250
WS/WE 45-N 260

PG 13.5; terminals

Sender	Receiver

Sender:
1 L+
2 M
3
4
5
6 TE

Receiver:
1 L+
2 M
3 Alarm
4 Q
5 Q̄
6

See chapter Accessories

Mounting systems
Special accessories

Technical data — WS/WE 45

| Technical data		P 250	P 260	N 250	N 260
Scanning range, max. typical	350 m				
Sensitivity	Adjustable				
Light source[1], light type	LED, infrared light				
Light spot diameter	Approx. 4.5 m at 300 m				
Angle of dispersion	Approx. 0.9°				
Supply voltage V_S	10...60 V DC[2]				
Residual ripple[3]	$< 5\ V_{SS}$				
Current consumption[4]					
sender without heating	≤ 50 mA		■		■
sender with heating	≤ 250 mA	■		■	
receiver without heating	≤ 50 mA		■		■
receiver with heating	≤ 250 mA	■		■	
Switching outputs	PNP, Q and Q̄	■	■		
	NPN, Q and Q̄			■	■
Output current I_A max.	200 mA				
Response time[5]	≤ 500 µs				
Max. switching frequency[6]	1000/s				
Pre-failure signalling output	Alarm				
Max. output current I_{Alarm}	100 mA, open collector				
Insufficient light received	Flashes at approx. 5/s, switch to V_S				
(Reserve < 50 %)					
Test input »TE«, sender OFF	PNP: Test input to 0 V	■	■		
	NPN: Test input to V_S			■	■
Connection type	Terminal connection				
VDE protection class	⊕				
Circuit protection[7]	A, B, C				
Enclosure rating	IP 67				
Ambient temperature T_A	Operation − 25 °C...+ 55 °C[8]				
	Storage − 40 °C...+ 70 °C				
Weight	Approx. 800 g				
Front lens heating		■		■	
Housing material	Metal housing				

[1] Average service life 100.000 h at $T_A = + 25$ °C
[2] Limit values
[3] May not exceed or fall short of V_S tolerances
[4] Without load
[5] Signal transit time with resistive load
[6] With light/dark ratio 1:1
[7] A = V_S connections reverse-polarity protected
B = Output Q and Q̄ short-circuit protected
C = Interference pulse suppression
[8] Up to 140 °C with cooling plates (see Accessories)

Scanning range and operating reserve

Operating range
Scanning range, max. typical

Operating range
Flashing mode
Scanning range, max. typical
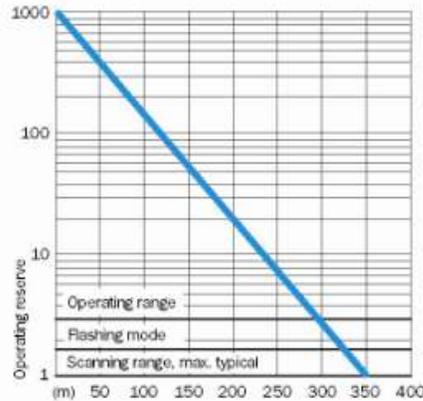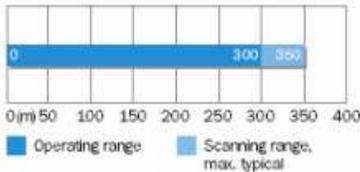
Order information

Type	Order no.
WS/WE 45-P 250	1 010 983
WS/WE 45-P 260	1 010 985
WS/WE 45-N 250	1 010 982
WS/WE 45-N 260	1 010 984

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**Scanning range
350 m**

Through-beam photoelectric switches

- Robust metal housing
- Red light
- Adjustable sensitivity
- Front lens heating, optional

Dimensional drawing

53	30	4

60

2 3
33
1
44

105

M6

83
105

4

11
21

28 | 25
98

A

A

3 5

6

33.4 | 19
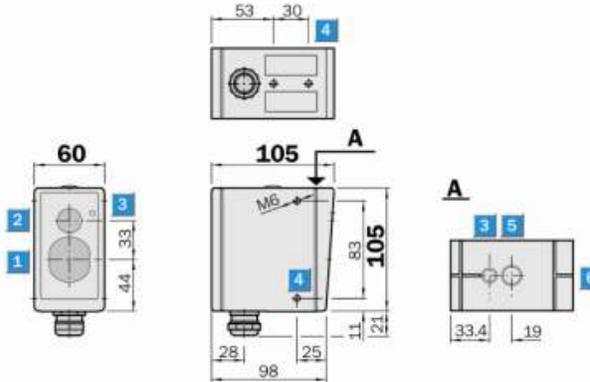
Adjustments possible

| WS/WE 45-R 250 |
| WS/WE 45-R 260 |
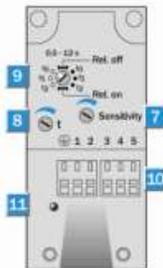
9
8 t Sensitivity 7
1 2 3 4 5
11
10

0.5 – 12 s Rel. off
Rel. on

1 Centre of optical axis, sender (WS)
Centre of optical axis, receiver (WE)
2 View finder lens
3 LED signal strength indicator
4 M6 threaded mounting hole – 8 mm deep
5 Eyepiece for alignment aid
6 Alignment sight
7 Sensitivity adjustment
8 Time adjustment
9 Time delay selector switch
left: light-switching, right: dark-switching
10 Terminal strip
11 Status indicator

Switch-selectable time delay

0.5 – 12 s

t_0 without time delay
t_1 ON-delay when object enters detection zone
t_2 OFF-delay when object leaves detection zone
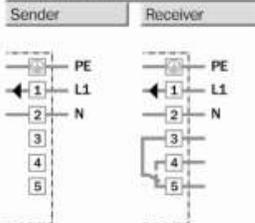
Connection type

| WS/WE 45-R 250 |
| WS/WE 45-R 260 |

See chapter Accessories

| Mounting systems |
| Special accessories |

PG 13.5; terminals
| Sender | Receiver |

Sender:
PE
1 L1
2 N
3
4
5

Receiver:
PE
1 L1
2 N
3
4
5

Technical data	WS/WE 45	R 250	R 260								
Scanning range, max. typical	350 m										
Sensitivity	Adjustable										
Light source[1], light type	LED, infrared light, pulsating										
Light spot diameter	Approx. 4.5 m at 300 m										
Angle of dispersion	Approx. 0.9°										
Supply voltage V_S	24…240 V UC (+ 10 %, − 25 %)										
Power consumption											
sender without heating	≤ 3 VA										
sender with heating	≤ 6 VA										
receiver without heating	≤ 3 VA										
receiver with heating	≤ 6 VA										
Switching outputs	Relay, SPDT, isolated[2]										
Max. switching voltage	AC: 250 V / DC: 120 V										
Switching current	4 A / 240 V AC o. 24 V DC										
Max. switching capacity	AC: 1000 VA / DC: 100 W										
Response time	≤ 10 ms										
Max. switching frequency[3]	10/s										
Connection type	Terminal connection										
VDE protection class	⊕										
Circuit protection[4]	A, C										
Enclosure rating	IP 67										
Ambient temperature T_A	Operation − 25 °C…+ 55 °C[5]										
	Storage − 40 °C…+ 70 °C										
Weight	Approx. 800 g										
Front lens heating											
Housing material	Metal housing										

[1] Average service life 100.000 h at T_A = + 25 °C
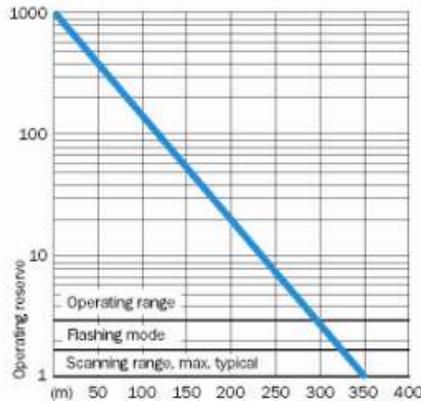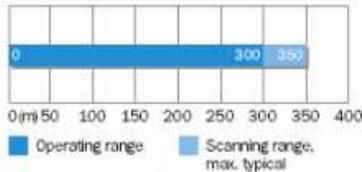[2] Provide suitable spark suppression for inductive or capacitive loads
[3] With light/dark ratio 1:1
[4] A = V_S connections reverse-polarity protected
 C = Interference pulse suppression
[5] Up to 140 °C with cooling plates (see Accessories)
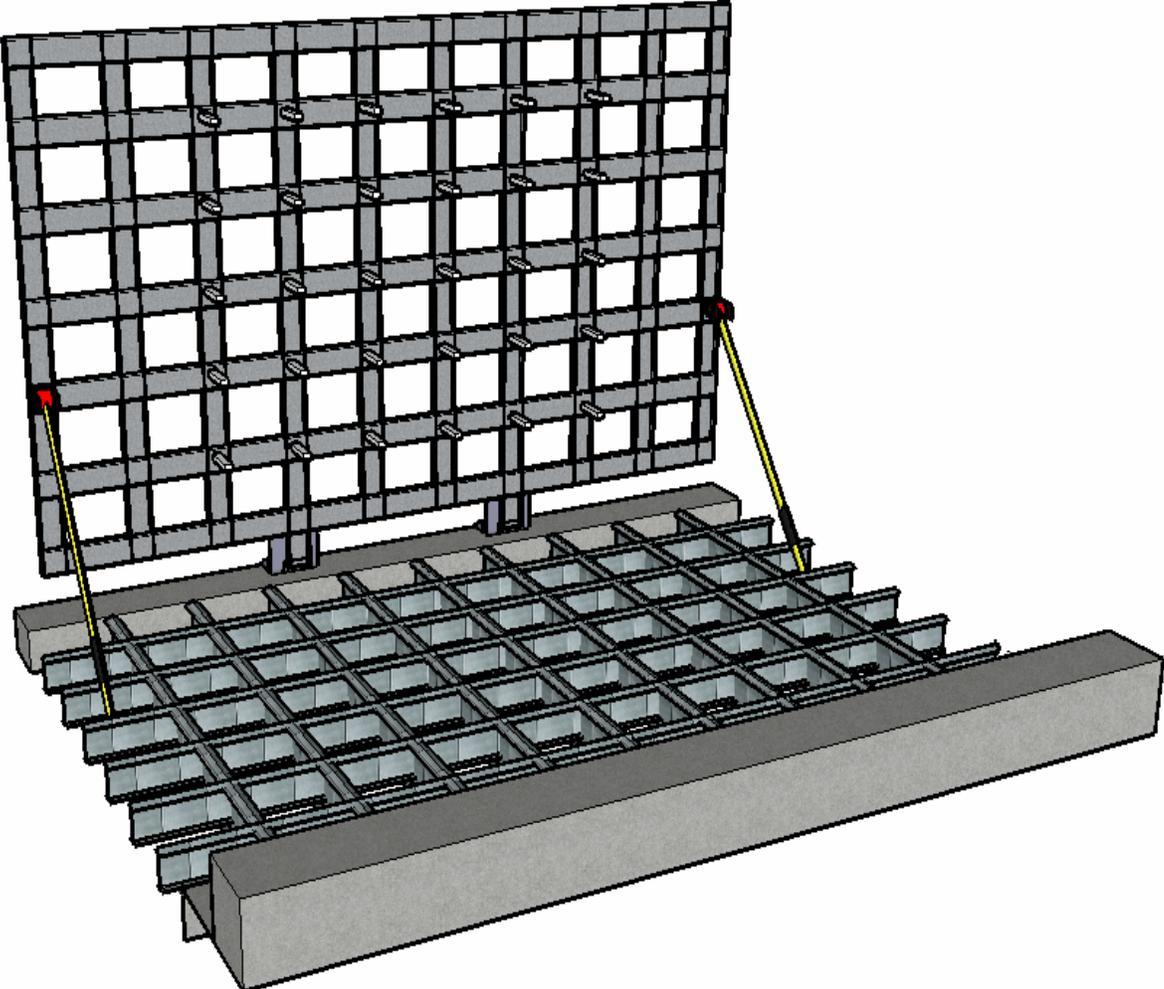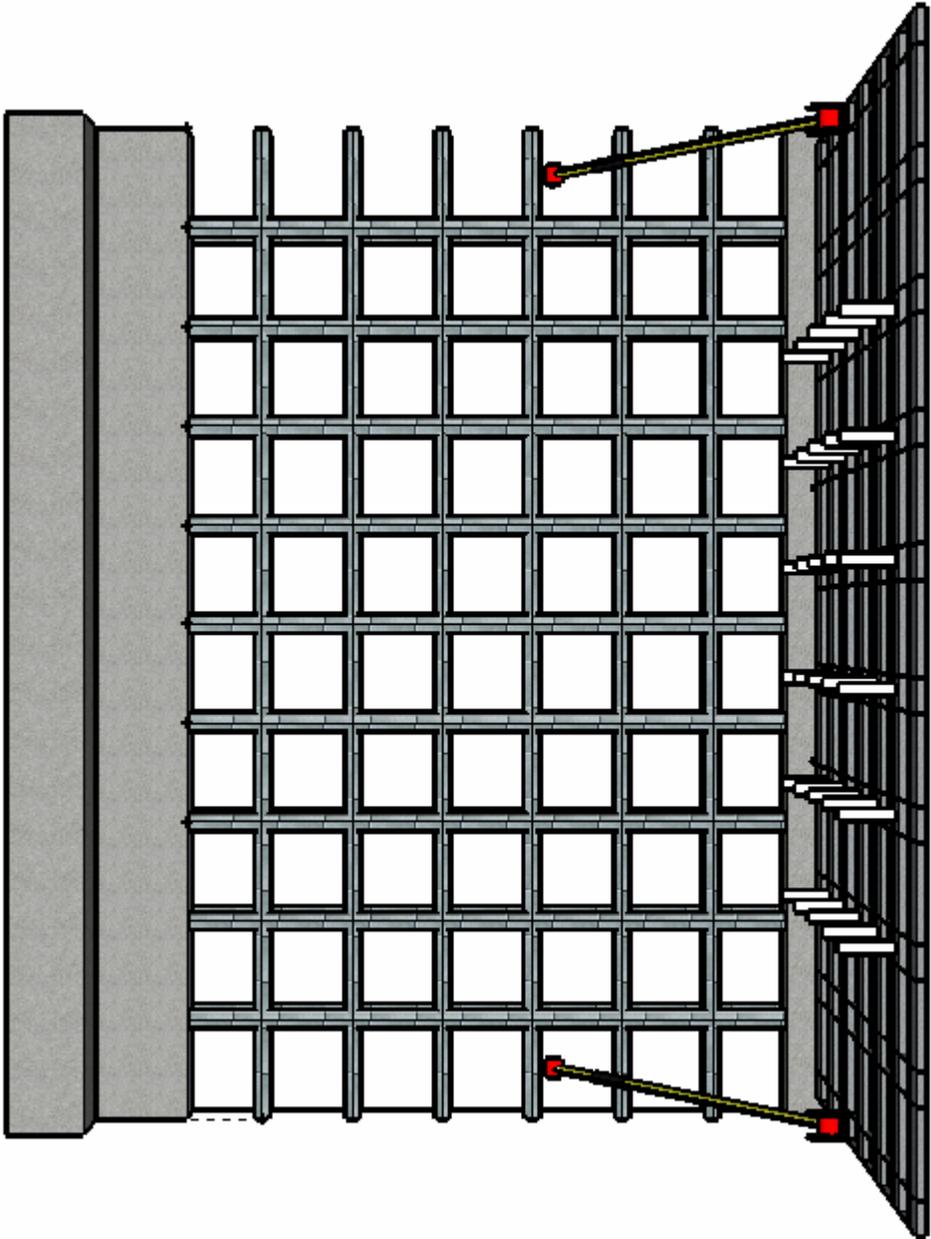
Scanning range and operating reserve

■ Operating range ■ Scanning range, max. typical

Order information

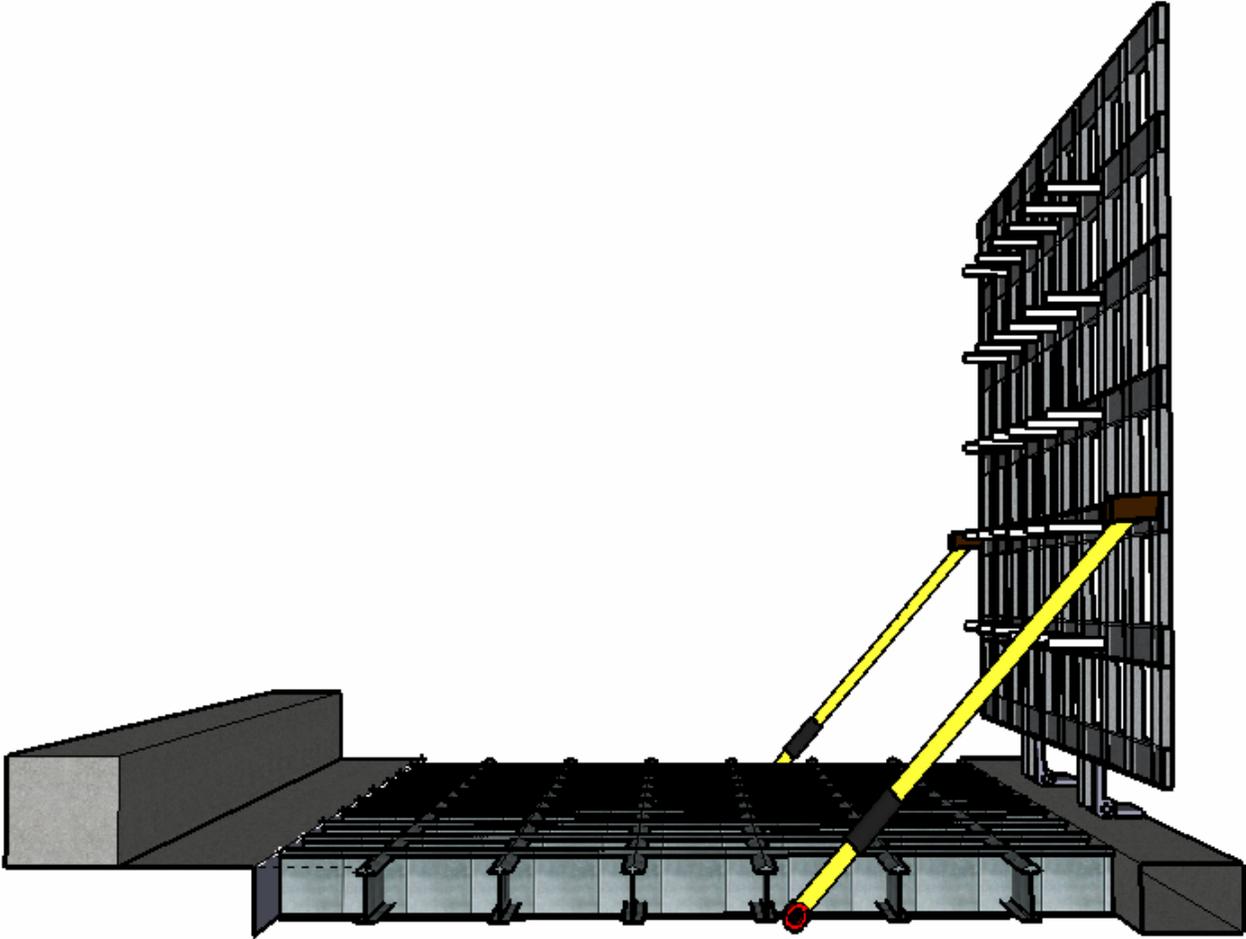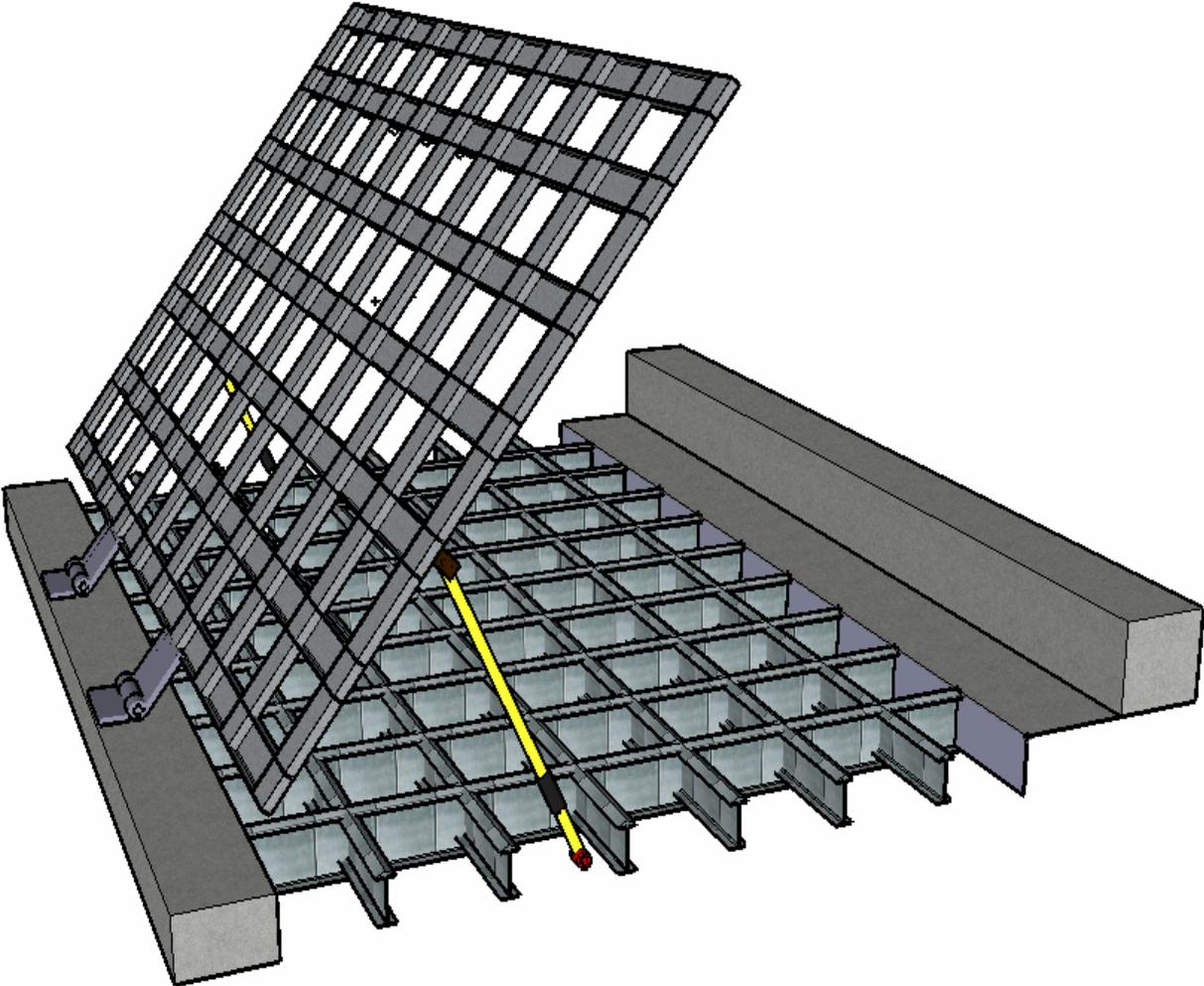| Type	Order no.
WS/WE 45-R 250	1 010 994
WS/WE 45-R 260	1 010 995

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Appendix K – Main Frame Model

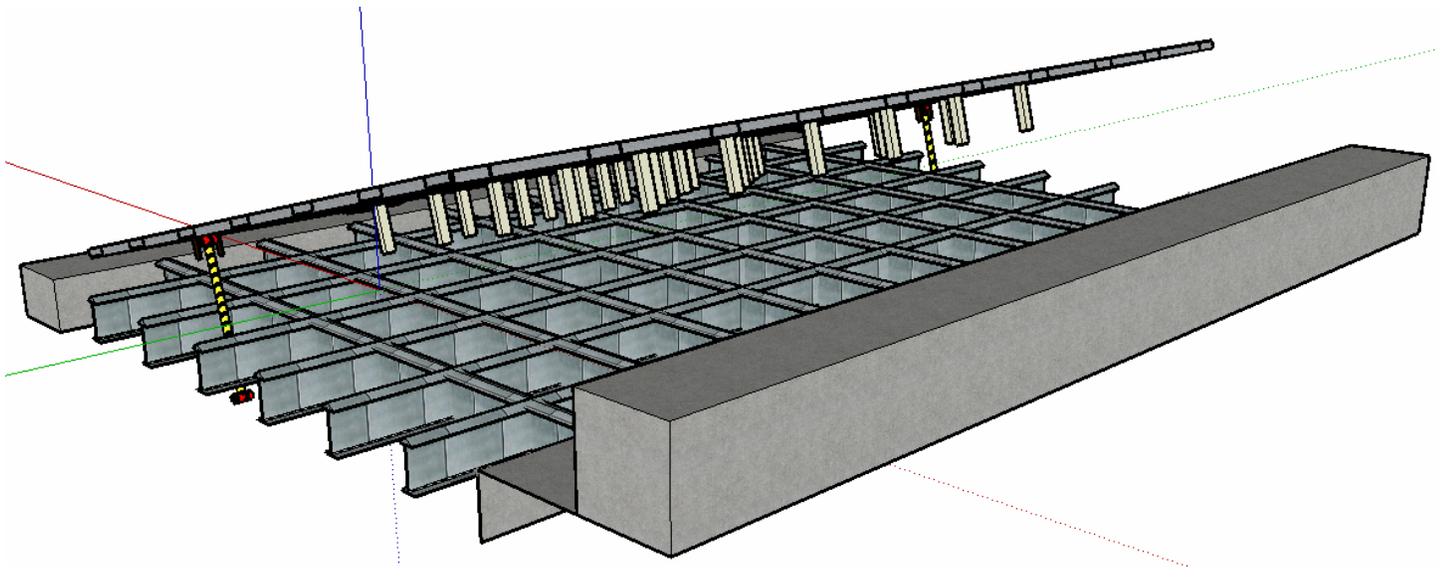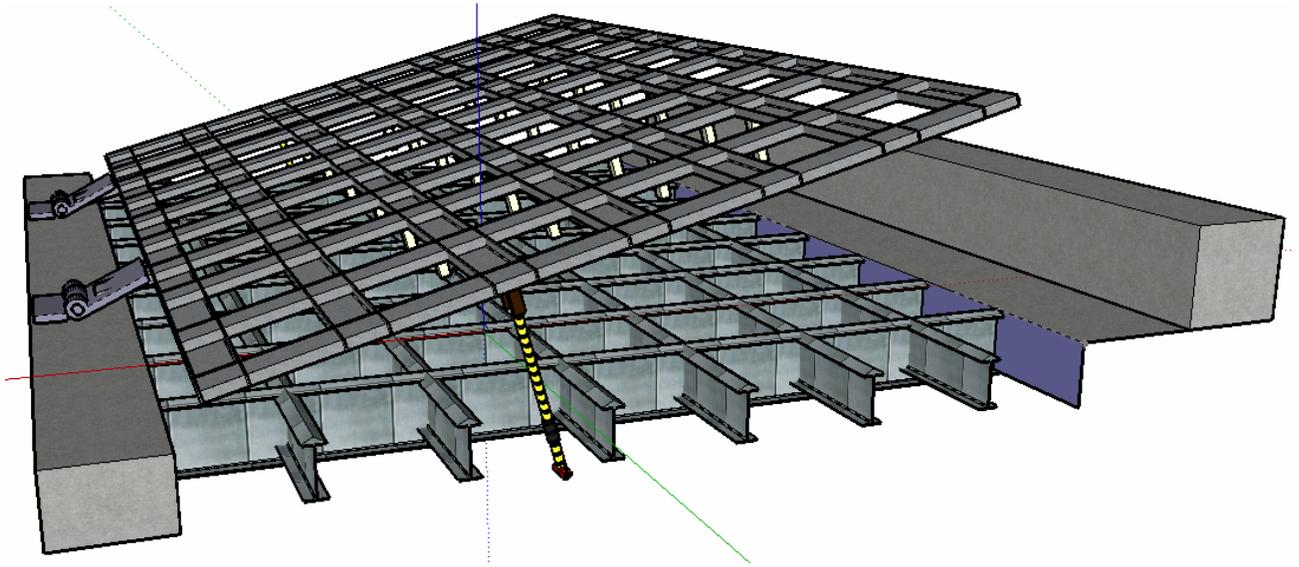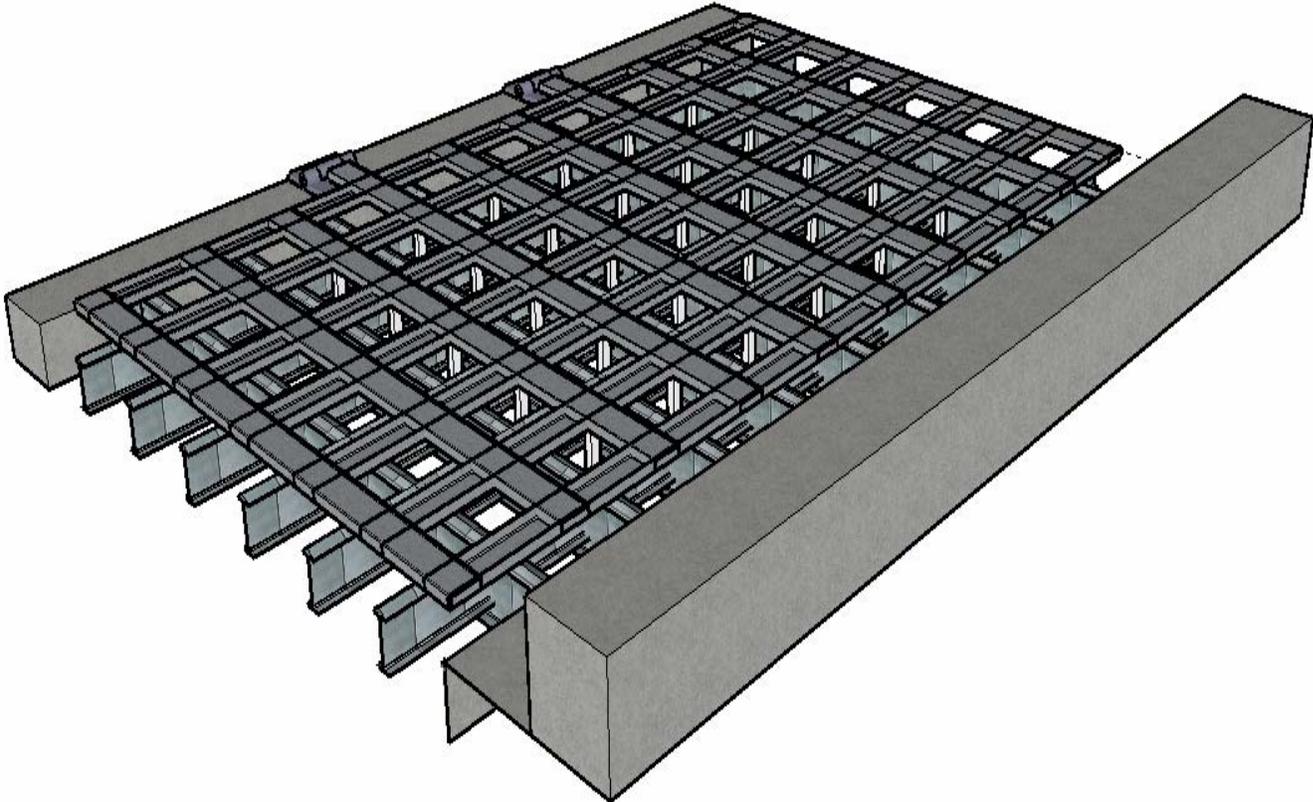Model – ISO View:

Model – Top View:

Model – Side View
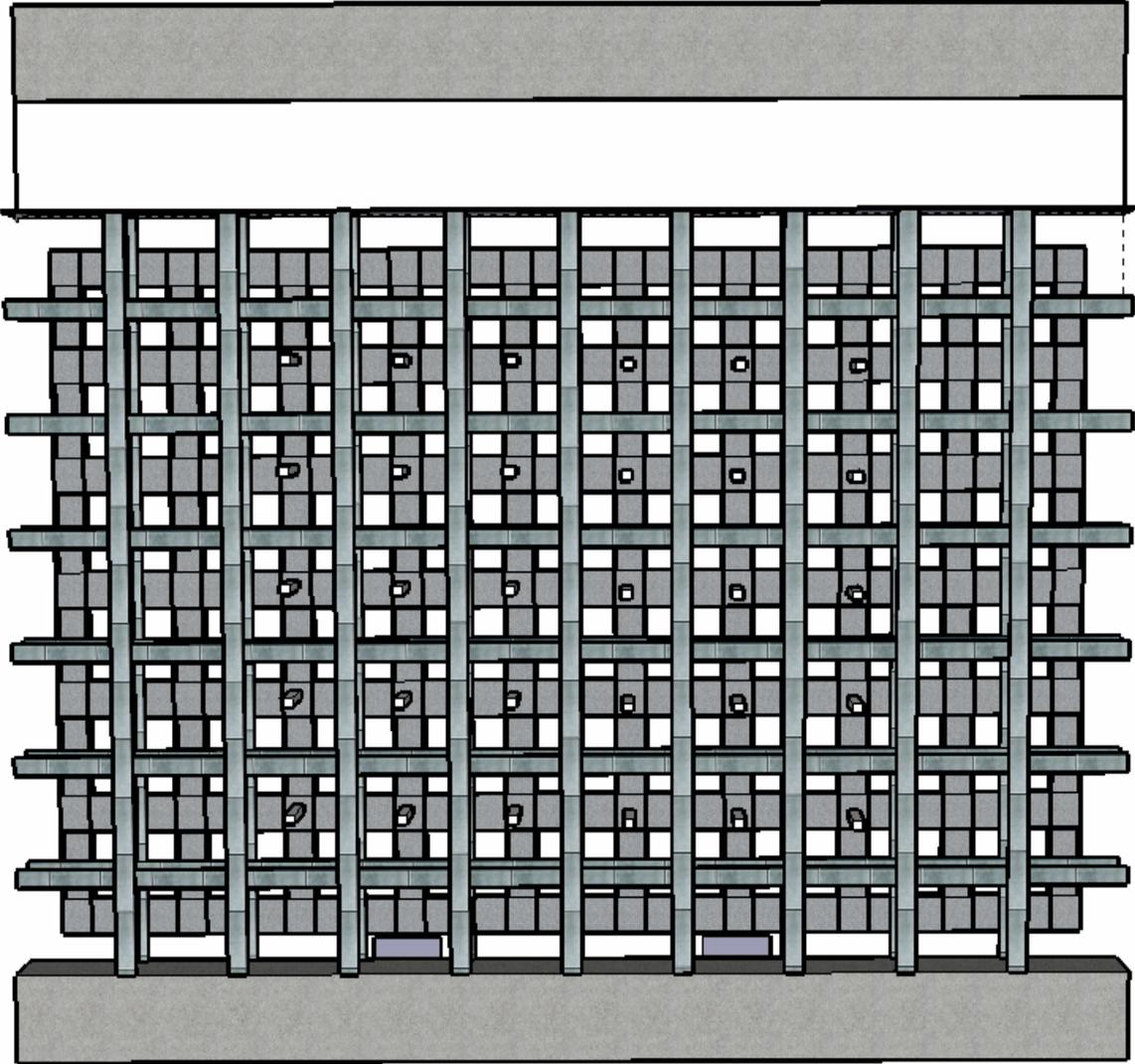
Model – Lowering of frame

K.6

Model – Fully Lowered

Model – Bottom View showing picks in grizzly holes

Appendix L – Problems faced by the Coal Mining Industry

Problems faced by the Coal Mining Industry

Coal mining is not always possible wherever coal is present and is typically susceptible to certain constraints, for example:

Dip of strata

Due to current machinery, a permanent feedback is required.

Faulting

If a fault hits a rock with a coal seam inside, the coal seam moves. Machinery trying to mine the coal may not be able to get at it if the coal has faulted off anywhere but to the side (if it is above or below it cannot manage this).

Water table

If the water table is too low, the mine is full with water. While mining, water needs to be constantly pumped out and this is expensive.

Washout

If a tributary or river changes course and cuts into the swamp material that will form coal, the coal seam is not fully formed and there may be a problem with mining it.

Thickness of seams

If the seams are too thin there may be an economic problem with mining it (it is worth less than the cost of the workers or petrol and is worthless.

Splitting of seams

If the seam splits, due to a delta collapsing, sand and silt sediments pile up on top until that area is covered by coal again. This may make all or part of the coal seam uneconomical to mine (as it is too thin).