Feasibility study of dump height reduction systems

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KTH Industriell teknik och management	**Examensarbete MMK 2014:88 MKN 122** **Konstruktionsstudie av höjdreduktionssystem för dumper** Dimitrios Karagiannis	
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Sammanfattning

Detta examensarbete i maskinkonstruktion var en förstudie, som genomfördes på uppdrag av Atlas Copco Rock Drills AB i Örebro. Förstudien bygger på ett patenterat förslag till en ny design, som skulle göra det möjligt för Atlas Copcos gruvfordon att verka i låga underjordiska gruvmiljöer. Patentet byggde på en helt ny typ av konfiguration, som var avsedd att eventuellt implementeras på vissa gruvfordon. Den nya konfigurationen skulle göra det möjligt att vika och minska lastflakets storlek före dumpningsfasen. Syftet med denna studie var att använda olika tekniska metoder för att avgöra om denna nya flakidé skulle vara ett intressant alternativ för Atlas Copcos framtida generationer av gruvdumpers.

Nyckelord: *gruvbrytning, gruvtruck, baklastning, lastkonfiguration, lossningsmetod*

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Abstract

The following Master Thesis project was carried out on behalf of Atlas Copco Rock Drills AB in Örebro, and in collaboration with KTH – Royal Institute of Technology, Stockholm. This project was a feasibility study based on a patented proposal for a new box design that would allow for Atlas Copco Minetruck vehicles to operate in low ceiling underground mine environments. This proposal was based in an entirely new box configuration with the potential of being introduced at Minetruck vehicles. The configuration of this box would allow it to fold and reduce its size prior to the dumping phase of the material. The aim of this study was to use various engineering methods in order to determine whether this new box idea would be an interesting Minetruck box alternative for the future vehicle product range of Atlas Copco.

Keywords: *mining, mine truck, backfill, box configuration, dumping method*

FOREWORD

First of all, I would like to thank my industrial contacts at Atlas Copco Rock Drills AB, Mr. Jimmy Ördberg and Mr. Fredrik Green for giving me this amazing opportunity to be involved in such a great Master Thesis project and for their kind support and help throughout it. I would also like to thank every person from the design and analysis departments at Atlas Copco Örebro for their kind assistance. Next, I would like to thank my KTH supervisor Mr. Ulf Sellgren for his support during the project.

Last but not least, I would like to take this opportunity and give a big thank you to my family for their great support throughout all these years.

Dimitrios Karagiannis

Sweden, October 2014

NOMENCLATURE

This part of the report includes the various notations and abbreviations used during the writing of this Master Thesis report.

Notations

Symbol	***Description***
MPa	Pressure in Mega Pascal
bar	Pressure in bar
m/s^2	Acceleration in meters per second
mm	Length / distance in Millimeters
m	Length / distance in Meters
kg	Mass in Kilograms
t	Mass in Tons
m^3	Volume in cubic meters

Abbreviations

CAD	Computer Aided Design
FEA	Finite Element Analysis
2D	Two Dimensional
3D	Three Dimensional

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1 INTRODUCTION

This chapter includes the background, purpose delimitations and methods used for the completion of this Master Thesis Feasibility Study.

Atlas Copco is a Global organization that dates back to 1873. Throughout the years, the company has expanded its business into four business areas ranging from Construction and mining, all the way to assembly tools. Located at Orebro, Sweden, Atlas Copco Rock Drills AB is part of the construction and mining business area.

The office and assembly station at Orebro, works as the headquarters of the URE (Underground Rock Excavation) division and its where most of the design work takes place. A range of mining products used in the complete mining cycle are developed and built at Orebro. Some of these products include various in size drilling rigs, Charging rigs, Loaders, Scaling rigs and Minetruck vehicles. The Minetruck vehicles come in a range of different cargo capacity sizes and are designed to be operated below the ground by a single person.

In a deep underground mine, gathering and dumping the blasted rock is more challenging than in an open pit mine environment. The narrow passages connecting the underground stations make the transportation of disintegrated rock harder. Recently, the market demand in the underground mining industry has shown that when it comes to Minetruck vehicles, the customers prefer larger capacity trucks which occupy less space. According to customers, the unloading stations are much larger in size than an average mine tunnel and they are built so that the tipping receptacle of a truck can reach to its upright position and empty the gathered material. The engineering effort and working hours spent to create those rooms with the extra ceiling height is critical. Being able to dump the gathered material in a more confined space will increase productivity and ease the whole mining operation since high ceiling unloading stations will no longer be necessary.

Driven by the customer need, to create a more flexible vehicle for transporting disintegrated material (else known as Ore) underground, Rock Drills AB has investigated a number of ways to empty the rear receptacle of a Minetruck without occupying much space.

Published at September 2013, a patent owned by Atlas Copco has described the placement of a hinge system on a vehicle's box and the use of various ways to 'fold the box' while unloading the transported material in a way that its outer size will be reduced. The whole point of this idea is to have a box that requires less ceiling space while operating and therefore make the Minetruck more usable at low underground mines. If succeeded, this new feature will improve the overall mining operation, since the miners will no longer have to build special high ceiling unloading stations within the mine and therefore save valuable time. Another advantage of such system can be the use of Minetruck vehicles in backfilling applications. Furthermore, in case of a sudden breakdown on the vehicle, the miners will be able to unload its cargo anywhere in the mine before servicing.

1.1 Background

This feasibility study represented the initial step towards the design of the folding box system and gave a first view of its advantages, disadvantages, design challenges, etc for a specific type of Minetruck Vehicles. The plan was to consider the MT42 Minetruck product as the ‘basis’ of this new box layout and optimize any components or methods used to fit its characteristics and specifications. The process of optimizing the patented design to function within the current vehicle has a number of challenges that need to be considered.

The challenges of modifying the box unit in order to reduce its dumping height were many, considering the fact that the new layout would ideally be launched as an option in the current Minetruck range. Modifying the box area was necessity, however, altering the chassis structure, wheelbase, and other important factors could potentially bring up compatibility issues and therefore increase complexity and price.

Another challenge expected was the fact that the box area would have to be divided into two sections according to the patent claims. This act, would interfere with the structural rigidity of the box section and therefore more support material would be required. A general observation is that the addition of material to the vehicle’s structure, eventually limits its ore carrying capacity.

Minetruck vehicles are all have designed to operate in a narrow underground environment. Increasing the outer dimensions by the addition of other parts and components onto the current design would not be an acceptable modification. Therefore it was clear from the beginning of the study that the current outer dimensions of the box should not be increased.

So far, the rear frame and box area of the Minetrucks have never been designed to accommodate some of the components and features needed for the addition of a folding function. Finding possible mounting locations within the standard frame could potentially ease the manufacturing process later on.

Creating a compact solution was also very important for the further development of a concept to a product. Any exposed components can be very dangerous for workers operating in the same environment Furthermore vital component exposure in narrow spaces can lead to damaging the structure if coming in contact with the walls of the mine.

1.2 Purpose

The purpose of this Master Thesis project was to initiate a feasibility study that would show how the idea of the Folding Box patent could translate from paper, to a three dimensional CAD model given the current Minetruck chassis and box designs as a reference. The translation from 2D to 3D is an important step towards the realization of a concept or product. Completing a working CAD model can lead to some very important findings and show the potential of the concept as a future vehicle option. Perhaps the most important observations that can be gained by the use of a working CAD model are the structure weight and the folding function representation.

In order to create the new Minetruck Box design, past studies, patent papers and three dimensional models of the existing product were investigated to get a better view of the overall concept. Any crucial dimensional limitations, weight and other important factors were taken under consideration while designing the new layout. The detailed goals of this project are listed below:

- Document the current Minetruck box options
- Gather information on current layout specifications
- Investigate Folding Box patent paper
- Determine the customer demands
- Find possible folding configurations
- Translate 2D sketches of the concepts to 3D CAD models

- Assess models in FEA Environment
- Complete design by introducing any additional components to the conceptual design
- Collect data from new concept
- Compare the current products with the potential concept
- Determine the feasibility of the new design.

The deliverables of this Master Thesis were following:

A conceptual CAD model of the Folding Box patent based on the observations and calculations made during the project. Along with the requested CAD prototype, a thesis report was delivered to both KTH and Atlas Copco Rock Drills AB.

1.3 Delimitations

The main focus of this study was the rear section of the articulated Minetruck vehicles designed by Atlas Copco. This feasibility study was based on a proposed patent owned by Atlas Copco Rock Drills AB. The design layouts and techniques followed for the realization of the three dimensional model were all based on the ones described on the original patent paper. Any methods or techniques that did not match the description of the patent were not considered.

The CAD models created for the realization of the folding patent were all kept in a conceptual level. The reasons for the simplistic design approach were that this was a basic research study and that there was no time to design a detailed, functional box. Therefore the structure of the Folding Box Concept was modeled as a single part. Furthermore, due to lack of time, the reinforcement additions to the folding box design were kept in a simple design level and not much experimentation towards the optimal reinforcement was attempted.

The single model approach eased the Finite Element Analysis part of the project too. Assessing the rear end of the box structure as a single part on FEA was a task that took less time and the results were not far from an actual multi-component model.

During the FEA assessment, the formulas used to calculate the side load were provided by Atlas Copco Rock Drills AB Analysis team and will not be explained in detailed in this project. The vertical loading conditions followed a simpler approach by not considering any heap on the top of the Ore pile. This was done due to various formula complications and therefore the vertical loading condition is not as ‘aggressive’ as it should have been.

The secondary cylinders designed as folding action aids, were dimensioned simply by considering the ore in the box as a single body of an approximate mass. Due to lack of vital information such as ore friction, an approximate calculation was made and no factors of design were considered. If the concept was to be launched as a product in the future, a deeper investigation would have been followed on that matter.

A number of current range Minetruck Layouts were shown during the project. It is important to note that more of these products have been developed by Atlas Copco in the past; however the three shown were the most common.

The final verdict on the potential of the new design was decided among a group of people in the design and the analysis teams of Atlas Copco Rock Drills AB, including the author of this report.

1.4 Method

The first step of investigating the potential of the new Minetruck based patent before turning it into a future product was to initiate an Engineering Feasibility study.

For start, a study of the basic underground mine layout, typical mining plan and operations was completed. By learning more about underground mines and mining operations, details about the environment and routine of the Minetruck vehicles were revealed. Next, two dimensional drawings and three dimensional models of past and recent Minetruck products were studied. This helped in understanding how such vehicles operate and in gathering all important information for the later comparison between the current range products and the new concept. The original Folding Box patent and the hand drown sketches of the proposed concept layouts were carefully studied. In parallel, meetings with people from the marketing department of Atlas Copco Rock Drills were arranged. The aim of these meetings was to document the customer demands and make a list of the important parameters on which the new concept and the current product range were compared.

The next stage of the study was a concept generation phase. This stage included the implementation of all customer requests and other design features in two conceptual designs. The two concepts were designed and modeled as working 3D CAD models. [Pro Engineer, 2014]

With the concept generation stage completed an FEM assessment with the aid of ‘Pro Engineer Mechanica’ software took place. [Pro Engineer, 2014] The use of a Finite Element assessment helped in the investigation of the structural integrity and reveal potential problem areas that needed some attention or re-consideration. Once the most promising concept was selected, the model was completed with the addition of hydraulic cylinders, cylinder mounts, swing arms and other little modifications.

The final and perhaps most critical step for the whole study was the comparison assessment between the most promising Folding concept and the current product range layouts. All advantages, disadvantages and critical specification values were taken into account before the final decision was taken.

2 FRAME OF REFERENCE

This chapter includes the methods and tools used in order to deliver the end result of the thesis feasibility study are explained in this part of the report. .

2.1 Importance of Mining and its development

The industry of mining is known to be the most vital source for the extraction of mineral commodities and therefore all countries around the globe find it essential for their development. The use of extracted minerals has helped in the development of modern civilization and more specifically in the generation of electricity, in the construction of roads and buildings and in the production and growth products such automobiles. Being a large industry, mining gives the opportunity to people to start a number of associated businesses such as equipment maintenance, manufacturing and other related services as well as triggers the growth of word class universities specialized on relative subjects. Talking all the above under consideration we can understand the importance of mining. It is believed that as the extraction of mineral commodities continues, miners are now leaded to extract poorer in quality material which are more difficult to access and to process therefore the material price will rise. [Committee on Technologies for the Mining Industries, 2002]

This is where the advancement of technologies in mineral exploration plays an important role. Over the years, the improvement of mining and exploration equipment has enabled humans to reach remote deposits, deposits that we were not able to reach with older means of technology, some of them of completely new nature. Furthermore, the industry has been focused on applying efficient mining methods and using specially optimized mining equipment developed to deliver maximum performance and efficiency. Nowadays, mining machinery such as drilling equipment, transportation vehicles and other important rigs are all capable of working in more demanding environments, with more precision, reaching mineral deposits impossible to reach in the past. Furthermore, safety has been increased and mining environment is safer than ever before. This improved and more efficient approach in equipment design has shown a great reduction to the final material price, balancing out any other exploration obstacles. [Committee on Technologies for the Mining Industries, 2002]

2.2 Mining and its types

Breaking down mining, we come across its two main types, Surface mining and Underground mining. A number of sub-categories are present in each one of the two types depending on the deposit type. These sub-categories depend on the following: The type of the deposit, the depth on which the deposit is located, how strong the rock is, etc. In general terms, Surface mining is more ‘advantageous’ when compared to underground mining as it recovers a larger number of mineral deposits and it also provides a greater flexibility and safety. The development of underground Mines is more complex and it requires the addition of ventilation and other systems that are not required in Surface mining applications. However, with the mineral deposits on the upper levels of the earth being almost gone, the demand for underground applications eventually rises. [Committee on Technologies for the Mining Industries 2002]

2.2.1 Underground Mines and their layouts

The concept of an underground mining operation is used when mineral deposits are located in remote areas deep down the earth or in the case of other surface land limitations. A fact about underground mines is that they are all unique and their layout has to be planned for each one precisely [Atlas Copco URE, 2014]. The methods of underground mining are always adapted to the conditions of the rock, its size, its geometry and to the stability of the ore's body.

For carrying on with the construction of an underground mine, the right layout arrangement has to be planned. The construction of a power supply station, accessing tunnel infrastructure, ventilation, drain, pump and other facilities are some of the arrangements required in a modern underground mine [Atlas Copco Rock Drills AB, 2007]. Following the description of a general Underground mine layout is being analyzed.

Accessing the mineral deposits requires the construction of vertical or inclined shafts that start from the earth's upper surface and extend towards its center. These shafts are built to transport ore as well as waste to the surface in an efficient manner [Atlas Copco URE, 2014]. Efficiency plays a very important role in mining and therefore its layout and infrastructure has to be designed with efficiency in mind. All Drifts, Shafts, as well as ramps connected to stopes via other tunnels form the main layout of an underground facility as seen in Figure 1 below.

After the material is blasted in small pieces and loaded into mining vehicles, it is transported from the production stopes via a network of special passes, to what is known as the haulage level. Deciding the exact location of a haulage level in a mine is one of the most crucial steps and has to be decided in a very early stage since it is a permanent installation and one of the most critical stations within an Underground Mine. From the main haulage level, the material is then emptied from the back of the mining vehicle carrying it, to a station commonly known as the crusher, where it gets crushed and trimmed into smaller in size pieces before it gets further processed [Atlas Copco URE, 2014].

Next, the ore is being sent to a storage facility, else known as silo. From there, it is transferred with the aid of lifts to the surface and to a large conveyor belt that sends it into the production plant [Atlas Copco Rock Drills AB, 2007]. Using a lift to transfer the crushed ore to the production plant is a very common method used in underground mining. In some cases, lifts are replaced by long sweeping tunnels where truck vehicles are used to deliver the material to the production plant.

At this stage it is important to mention that out of the blasted rock gathered; only a small percentage is being used. The rest of the material that does not have any value in some cases is sent back to the tunnels and gets stored in old abandoned mine levels with the aid of mining vehicles. This process is commonly known as 'backfill'. The operation of backfill in Underground Mines, is a widely used process used to fill up the tunnels build within a mine after all the useful deposits have been collected. This is an important operation that stabilizes workings by preventing the risk of rock collapsing. Another advantage of backfill is the economy it offers by the reduction of the overall space in a mine. Once an old void is filled up with rock waste, the cost of ventilation for the whole mine as well as the time required to clear the air can be reduces significantly [Atlas Copco URE, 2014].

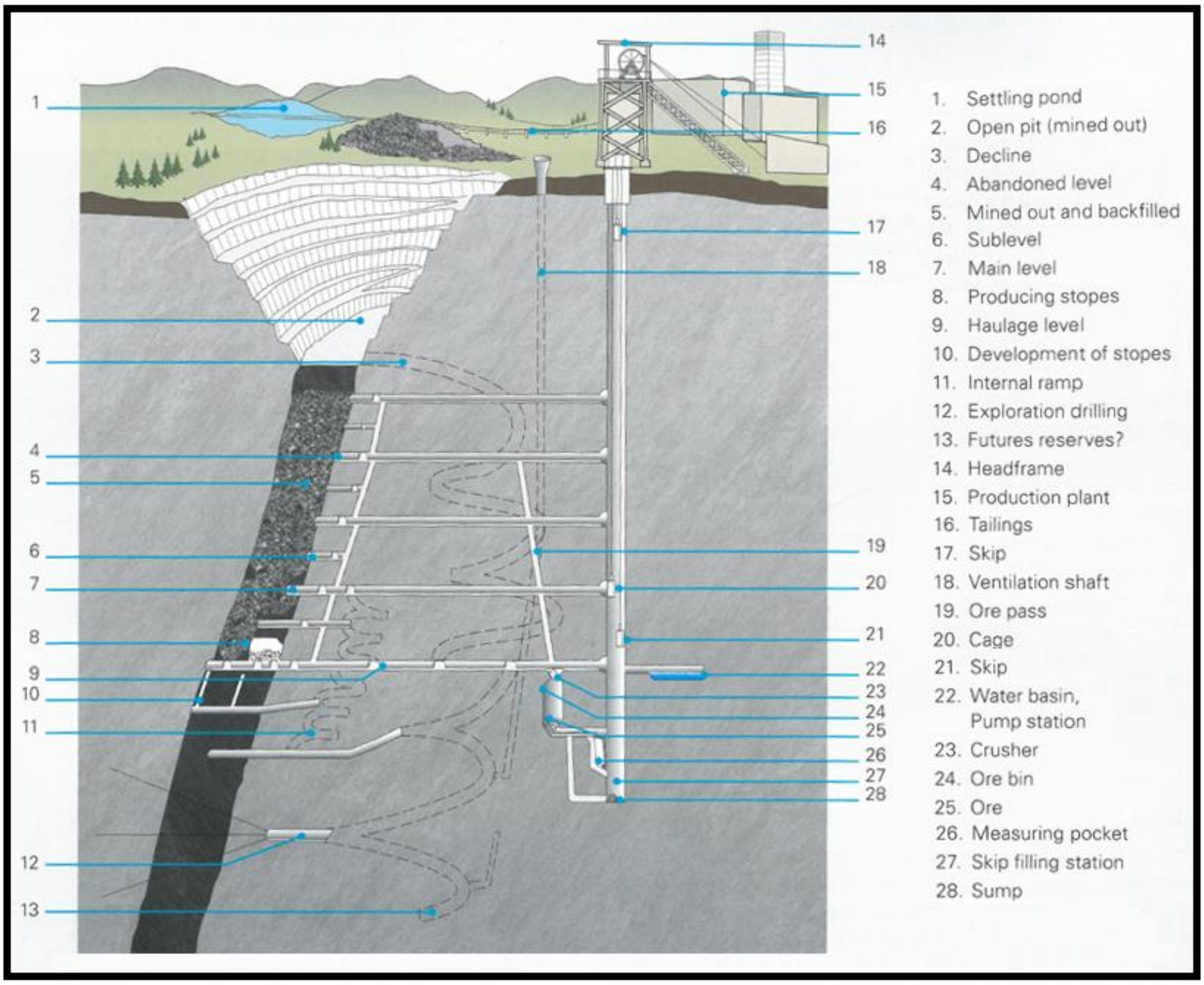


Figure 1: Basic infrastructure requirements for a typical underground mine [Atlas Copco URE, 2014]

2.2.2 Underground Mines – Hard Rock Mining plan

Once the mine layout plan is complete, all the important mining activities such as rock drilling, blasting, loading the ore and transporting it, are all executed according to a strict mining plan. Where the material handled is in a softer form, such as Salt, Potash, or the widely popular Coal, cutting and loading is being handled with the aid of mechanical means. In applications such as Hard-Rock, where this thesis research is based on, precise drilling and blasting with dynamite or ammonium-nitrate is being used. [Committee on Technologies for the Mining Industries (2002)]

Ore extraction in Hard-Rock applications requires a number of steps for its successful execution see Figure 2. The first step of the production cycle is drilling. Special drill rigs, perform a well-planned pattern of long holes through the walls of the mine with high precision. Next, with the help of another rig, specialists place explosives through the long holes. Once the area is evacuated, the rock is blasted by a controlled explosion. Next, the large ventilation system of the mine comes into picture, quickly clearing the area, making sure no harmful gasses are present in the mine tunnels. Next one of the most critical steps, known as material handling, is taking place. Material handling starts by mucking the blasted ore and loading it into mining trucks before being dumped into the crusher station for further processing. The cycle is then completed with the aid of a Scaling rig which improves the finish of the mine tunnels, a Shotcreting rig which applies a coating on the tunnel and the Bolting rig which mantles long beams on the walls and ceiling securing the area. Once completed, a typical underground tunnel is 4.5 meters in width and 4 meters in height.

It is important to know, that some mining plans are executed in a slightly different way. For example, after blasting the rock and ventilating the tunnels, if the passage created is very rough, a Scaling rig might be used to improve its finish before the Material handling phase begins.

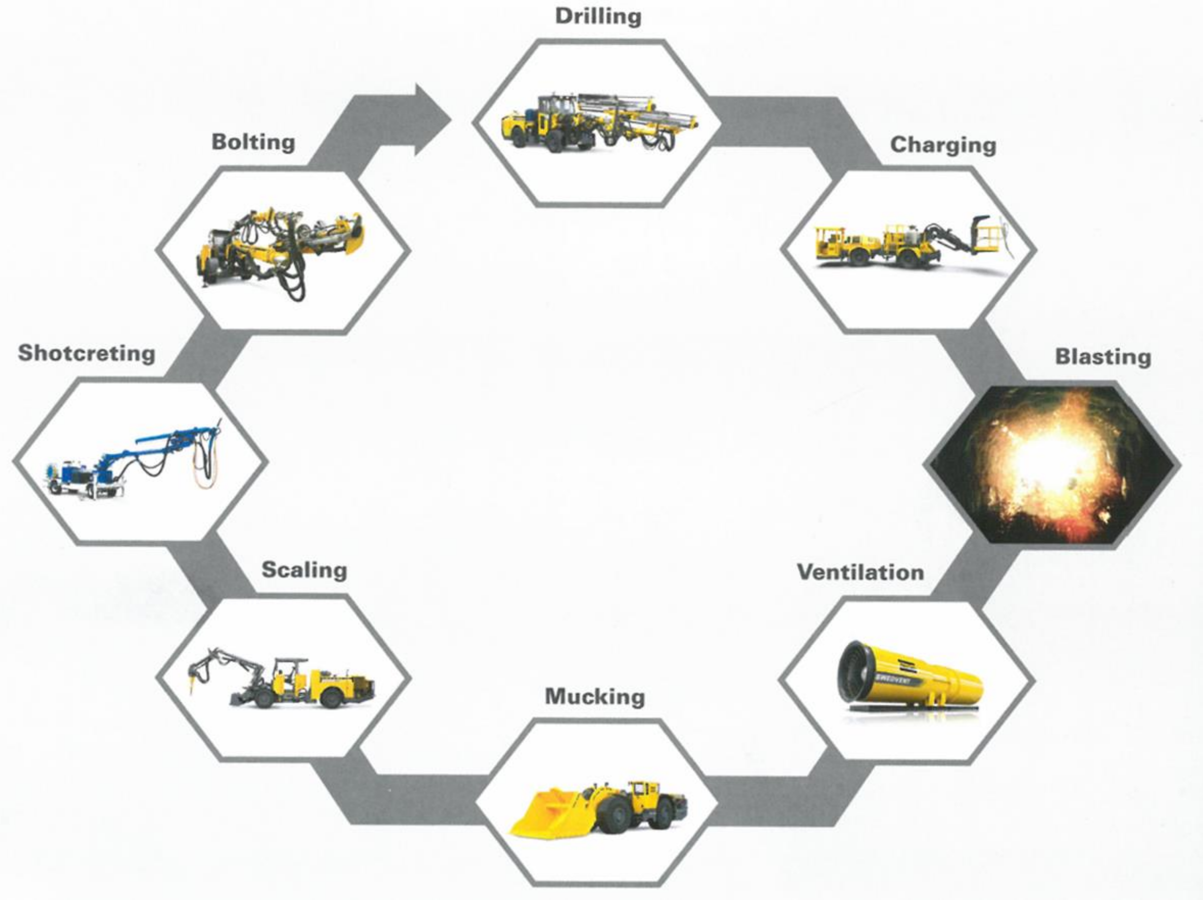


Figure 2: The sequential operations as performed in a typical underground mine [Atlas Copco URE, 2014]

2.3 The Atlas Copco Minetrucks

Atlas Copco offers a wide range of vehicles built to be used in various surface and underground mining operations. One of the most popular vehicles is the range of Minetrucks. Minetrucks are material handling trucks that come into different sizes and layouts depending on the customer and segment needs as well as safety and regulation standards. The smallest Atlas Copco Minetruck in production today is capable of transporting 20 metric tons of cargo, where the largest can handle up to 60 tons of cargo. Furthermore Minetrucks are designed to be working alongside other Atlas Copco products such as the Scooptram loader vehicles, to ensure maximum productivity in the working environment.

For the purpose of completing this Master Thesis feasibility study, the example of a specific truck was used as a reference. The reference vehicle on which all assumptions were based during this study was the Atlas Copco MT42 Minetruck. The reason behind this decision was the fact that an MT42 sits in between the 20-60 ton capacity range making it a good reference product for this thesis.

The MT42 is a large, articulated vehicle, capable of transporting a maximum of 42 metric tons of material and optimized for the construction and underground mining industry. It is purpose-built is to transport disintegrated material of various types from the excavation sites all the way to the underground or surface based unloading stations. Originally launched in 2010, the vehicle was designed for high productivity and fast work cycles. Its high power to weight ratio, help the Minetruck to overcome the physical obstacles of a typical mine and go through steep and slippery slopes easily, even when fully loaded. The overall layout of the MT42 can be divided into two main parts, as seen in Figure 3, the drivetrain section up front and the box section at the rear that it is being used for the transportation of material.

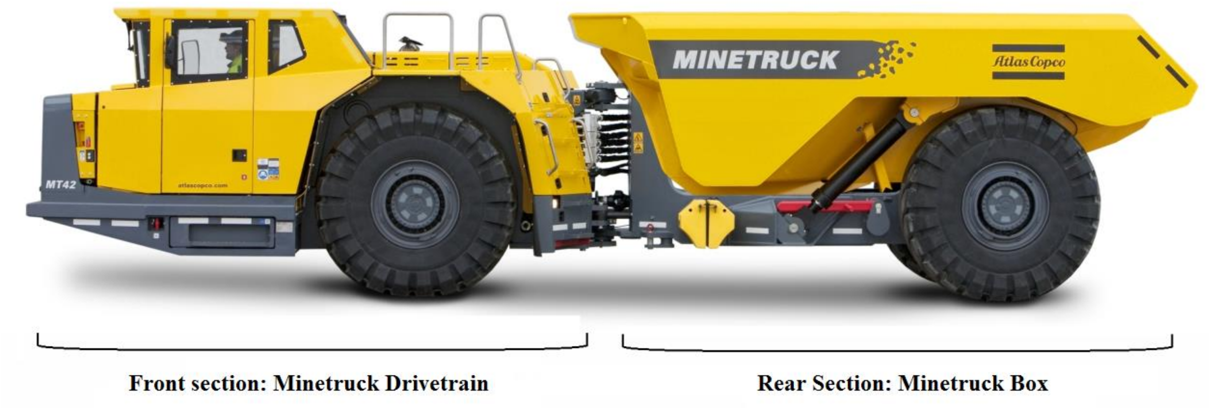


Figure 3: A side view of the Atlas Copco MT42 Minetruck vehicle with an older model box

2.3.1 Minetruck Dimensional Limitations

For the most of its lifetime, a Minetruck might be operating exclusively in an underground mining environment and therefore its design has been optimized to do so. As already mentioned in Chapter 2.2.2, a typical mine tunnel has a narrow 4.5 x 4.0 passage and this is why Minetruck outer dimensions are very critical for its function.

Due to the narrow spaces of a typical underground mine, a Mining vehicle with large outer dimensions, can face many space limitation issues while maneuvering in it. On the other hand, if the outer vehicle dimensions are too small, its ore capacity will be significantly reduced, resulting in a less efficient solution when it comes to the material handling phase of mining.

Taking the above information under consideration the MT42 Minetruck vehicle was designed with strict dimensional restrictions in mind. An example of those, as seen in Figure 4, is the width of both articulated sections that is strictly kept the same throughout the whole vehicle.

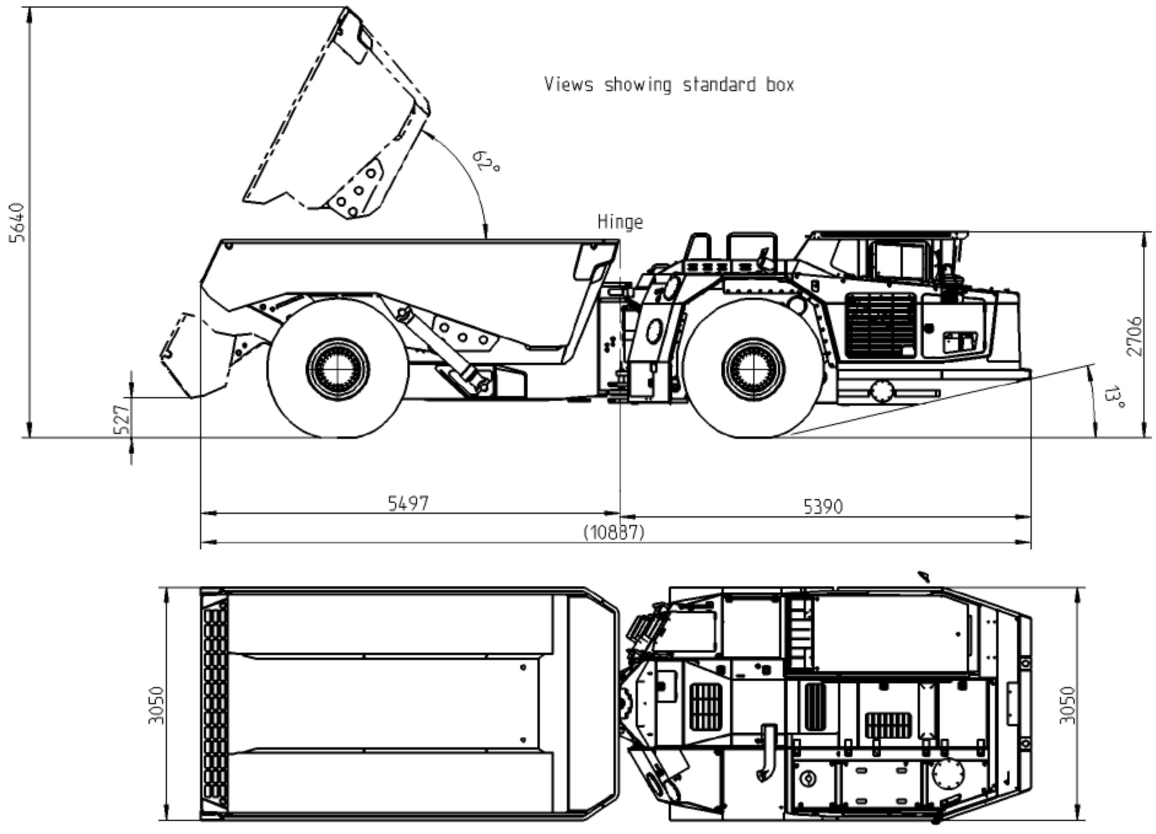


Figure 4: A top view and the basic dimensions of the reference vehicle, the MT42 Minetruck

2.4 Minetruck Existing Box Designs

Since this thesis was focused on the realization of a dump height reduction method, the main interest was on the rear section of the articulated Minetruck vehicle and more specifically on the box area. The box is the section of the vehicle which is used for the transportation of the disintegrated material extracted from the mining tunnels and therefore it is what makes the Minetruck vehicle useful throughout a mining cycle.

Throughout the years, a number of different Minetruck configurations have been developed in order to satisfy different customer needs in the underground mining segment. These configurations were all focused in the rear section of the minetruck vehicles optimizing it for a specific application. The three most common configurations found in the Atlas Copco product range are the:

- The Standard Box
- The Ejector Box
- The Teledump Box

It is common that different mines, handle different ore types and sizes, therefore, in order to further optimize these boxes, all configurations come in a range of different sizes.

2.4.1 Minetruck – Standard Box Design and Applications

Today, the Atlas Cocpo Standard Box configuration is the simplest of all available box types and the way it works does not differ much from the conventional trucks used for typical construction applications. Figure 5 illustrates a CAD model of the complete vehicle including its front and rear sections.

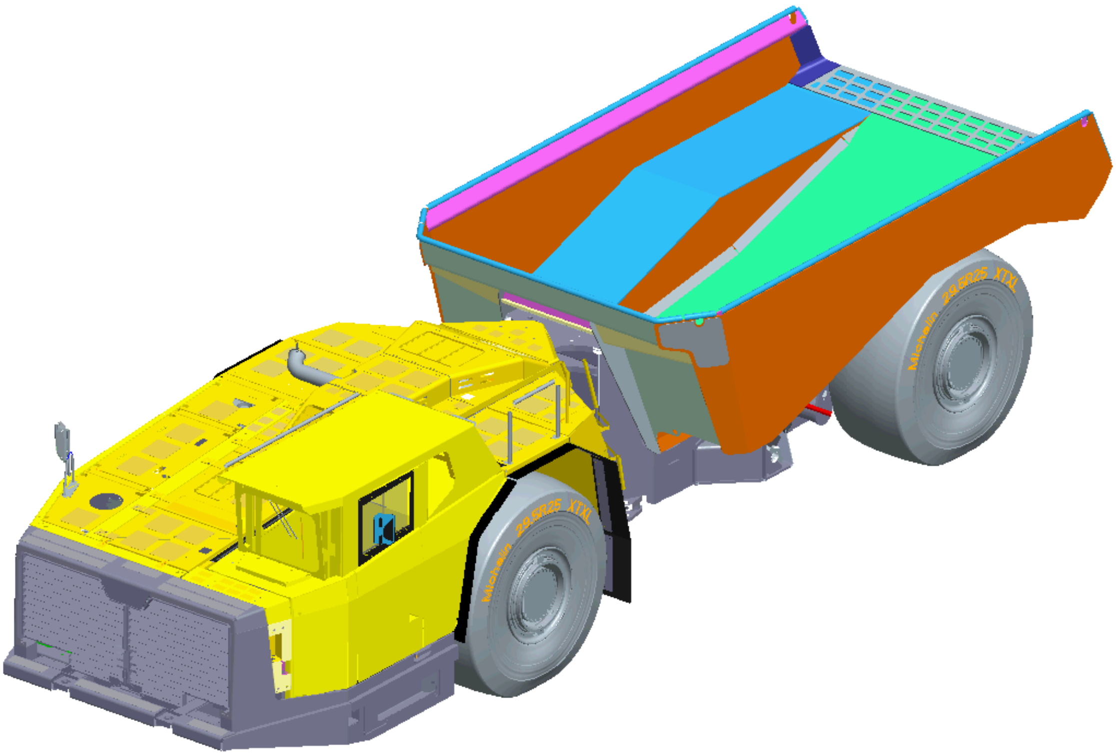


Figure 5: The complete CAD model of a Minetruck vehicle featuring a standard box rear section

Located at the rear part of the articulated vehicle, the standard box features a simple hinge positioned at the rear section of the frame allowing it to swing 62º degrees from its resting position in order to dump the material gathered behind the vehicle. The movement of the box is being guided by a set of telescopic actuators and a hydraulic system and controlled by the driver. This is a very simplistic and durable configuration used by most trucks around the world and can cope with the majority of applications in both surface and underground mining. Figure 6 illustrates the side view of the Standard Box & Rear Minetruck Chassis / Frame assembly along with the locations of the Pivot Point and Hydraulic Actuators.

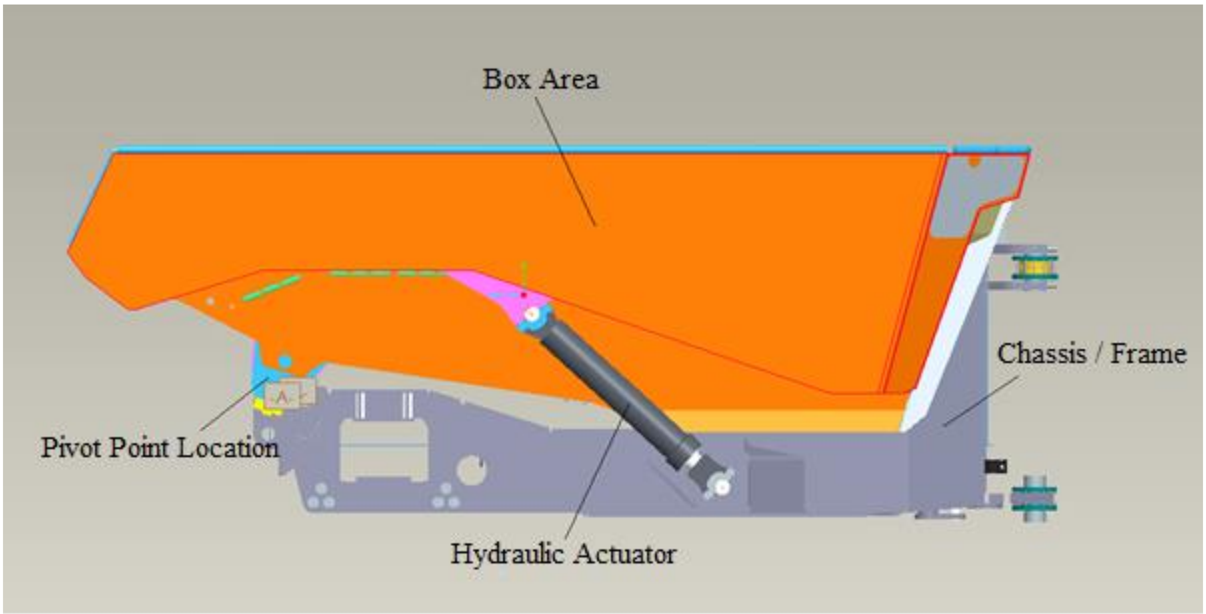


Figure 6: A side view of the Standard box configurations, mounted on the rear Chassis / Frame assembly

As seen in Figure 7 below, the standard box is made off multiple steel sheets forming together a large, open from the top box. The steel sheets are welded together and their thickness varies according to the structural importance of the area they are forming. It is important to mention that the overall geometry of the box area has been designed to distribute the ore weight in an efficient fashion across the Minetruck Structure.

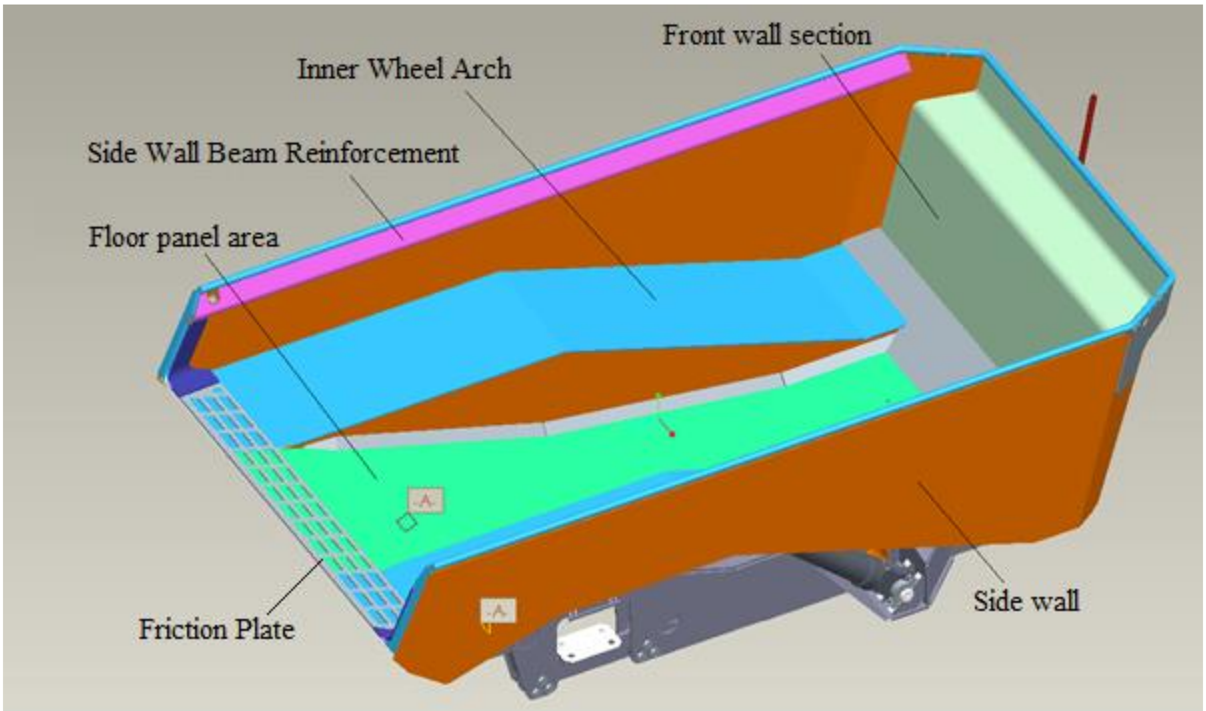


Figure 7: A general view of the Standard Box geometry and some of its vital panel sections.

Another important design feature of the standard box is its inner section geometry. What looks like a simple box, appears to be a pattern that allows for a smooth and efficient material flow, without leaving large quantities of ore in the box section once the unloading has been completed.

Trapped ore quantities left in a box are often referred to as carry-back and affect the overall efficiency and performance of a Minetruck vehicle. The less carry-back a box geometry has, the more efficient it is.

Underneath, see Figure 8, a set of long stiffener beams running across the box as well as other stiffener plates make sure that the structure does not deform under static and dynamic loading conditions. Furthermore, a thick steel plate welded on the upper frontal section ensures that the structure has a solid resting point onto the Minetruck chassis. This is also the part of the vehicle, where the material scale sensor is located.

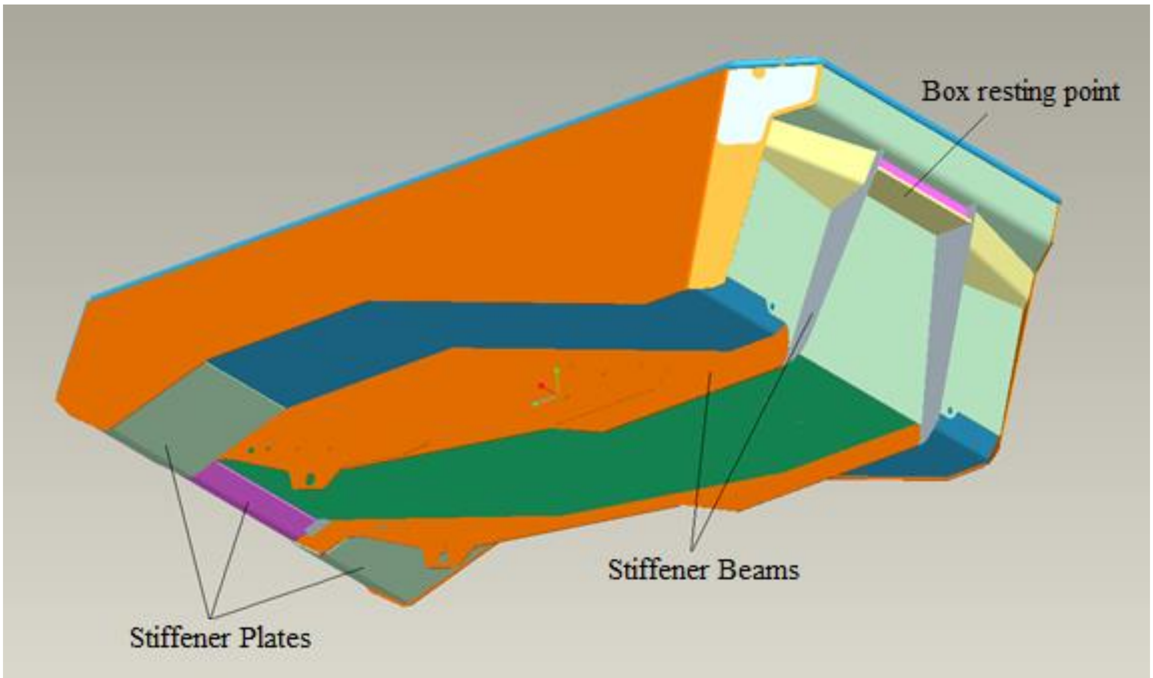


Figure 8: The underbody area of a Standard Box, its vital reinforcement features and resting points are illustrated and marked.

As seen from the data collected above, the Standard Minetruck Box configuration has a number of critical design features. Equally important to the design features is the performance specification numbers gathered by studying the three dimensional models, the two dimensional drawings and various data sheets.

One of the most important parameters measured in a newly designed box structure is the force applied on the rear axle of the vehicle. The rear axle used in Minetruck vehicles is one of the most critical components and over its life time has to withstand large loads, vibrations etc. The load limit of a rear Minetruck axle varies according to the loading capacity needs of the vehicle. When designing a new box, it is always important to check the axel loading allowances in order to determine the amount of ore that can be added to its box.

The following table, Table 1 includes all vital specification values related to the Standard Box configuration. These values were later used for the comparison assessment of the current product range and the new concept design.

Table 1: The most important performance specifications documented for the Standard Box configuration

Parameter	Units	Value
Ore Density	[1000Kg/m^3]	2.2
Volume of Ore Transported	m^3	19
Payload	Tons (t)	41.8
Structure Width	mm	3050
Dump Height	mm	5640
Structure Weight*	kg	5350
Dump Cycle Time	sec	16
Payload / Structure Weight	Ratio	7.8

*Note: *The value of structure weight documented above includes the complete Box structure, Mountings and pivots as well as the required Hydraulic cylinders and Cylinder Mounts used for operating the box. The rear Chassis structure, Wheels and axle were not considered.*

2.4.2 Minetruck – Ejector Box Design and Applications

Driven by the need to transport and dump ore in underground mines with low ceiling height and perform Backfilling operations, Atlas Copco in Sweden has recently launched a brand new box configuration known as the Ejector Box. The Ejector Box is a box structure mounted directly on the rear frame of an articulated vehicle and does not work with the principles of a tilting box and a smooth flow by gravity. Instead, this configuration has the unique feature of ejecting the gathered material out of the box with the aid of a hydraulically driven plate.

The ejector box, illustrated in Figure 9 below, consists of three main parts:

- The first is the box unit that features a uniform cross-section design all across the structure. This is the area where the material is loaded and stored until the vehicle reaches to a dumping station.
- The second part is the ejector plate, a moving platform designed to push the material through the rear part of the vehicle with the aid of a hydraulic system and two large telescopic cylinders.
- The third vital part for the ejector function is the large tailgate that is lowered with the aid of a hydraulic cylinder system to allow for the ejector plate to push the material out of the box area.

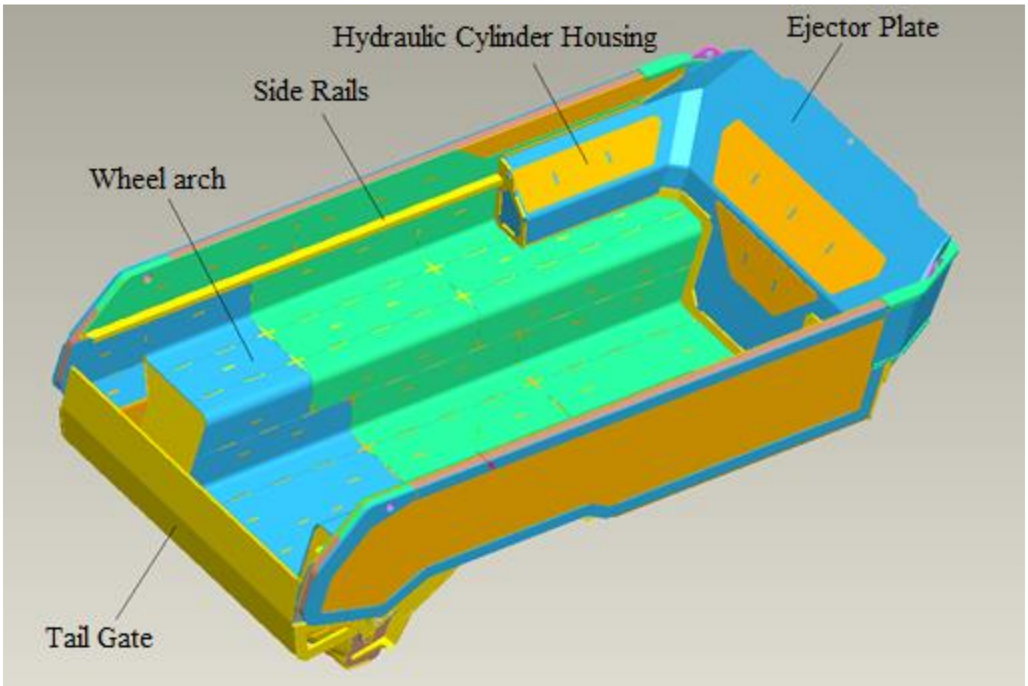


Figure 9: A general view of the ejector box configuration and its main design features

To begin the ejector process, the operator releases the tail gate. Once the gate has reached to the lowest position, the ejector plate travels all across the box, pushing the gathered ore towards the rear. Figure 10 illustrates the fully exerted plate and tail gate.

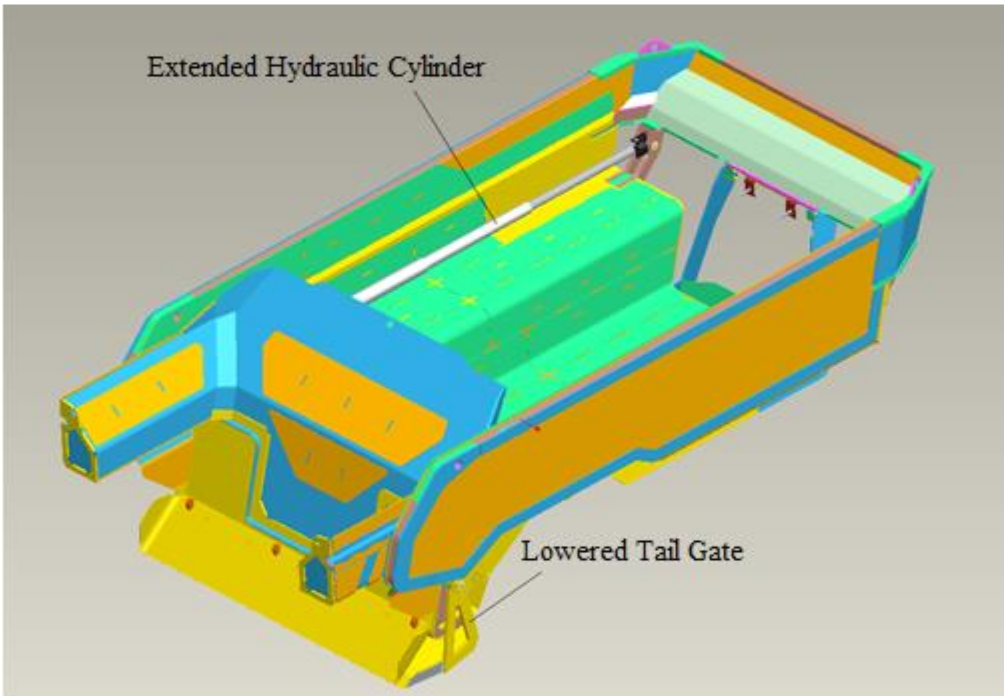


Figure 10: A simple illustration of how the ejector box works

As previously mentioned, for the completion of this feasibility study, equally important to the design features is the performance specification numbers gathered throughout drawings, CAD models and various documents. The rear axle used in the Ejector Box equipped Minetruck, is the same to the one used in the Standard Box configuration. Therefore, the axle itself can withstand the same maximum load, however, due to the additional features of this box configuration, its capacity and performance characteristics is different to the Standard Box. The following table, Table 2 includes all vital specification values related to the Ejector Box configuration. These values were later used for the comparison assessment of the current product range and the new concept design.

Table 2: The most important performance specifications documented for the Ejector Box configuration case.

Parameter	Units	Value
Ore Density	[1000Kg/m^3]	2.2
Volume of Ore Transported	m^3	17
Payload	Tons (t)	37.4
Structure Width	mm	3050
Dump Height	mm	2815
Structure Weight*	kg	9350
Dump Cycle Time	sec	30
Payload / Structure Weight	Ratio	4.0

*Note: *The value of structure weight includes the Box area, the Ejector Plate, the Tail Gate, Mountings, pivots, sliding rails and Hydraulic cylinders. The weight of the rear Chassis, Wheels and axle were not considered.*

2.4.3 Minetruck – Teledump Box Design and Applications

While looking through various Atlas Copco Minetruck products and designs, an interesting box configuration was found to be developed and produced in small units for the Canadian market. This product was based on an older and slightly different Chassis frame used in the Minetruck MT431/436. Although slightly shorter in size, this older chassis had a similar geometry and rear axle design. Specifically developed for the underground mining market this box type allowed the vehicle to reach in low ceiling tunnels and perform its transport, unloading and backfilling routine. The name given to this Minetruck configuration was Teledump and the idea behind was that it would be able to reduce its box size prior to dumping the ore inside an underground tunnel.

The main components of a Teledump box are the following:

- A secondary chassis working as a swinging platform on which the box is placed.
- A box divided into two sections Front and Rear.
- A simple tail gate pivoted on its top side.
- A set of cylinders for lifting the box in a similar way as the Standard box works.
- A set of cylinders dragging the front part of the box towards the rear reducing the overall size of the box area.

The box area is constructed by two separate parts, the front and the rear, with the front part being able to slide across the secondary frame and inserted in the rear section. Underneath the box area and mounted onto the secondary chassis, a set of hydraulic cylinders control the movement of the front section and help in the size reduction. Once the front part has been dragged towards the rear, the box is being lifted to an angle of 62° and the rest of the cargo is being emptied. Figure 11 below, illustrates a two dimensional drawing of this configuration.

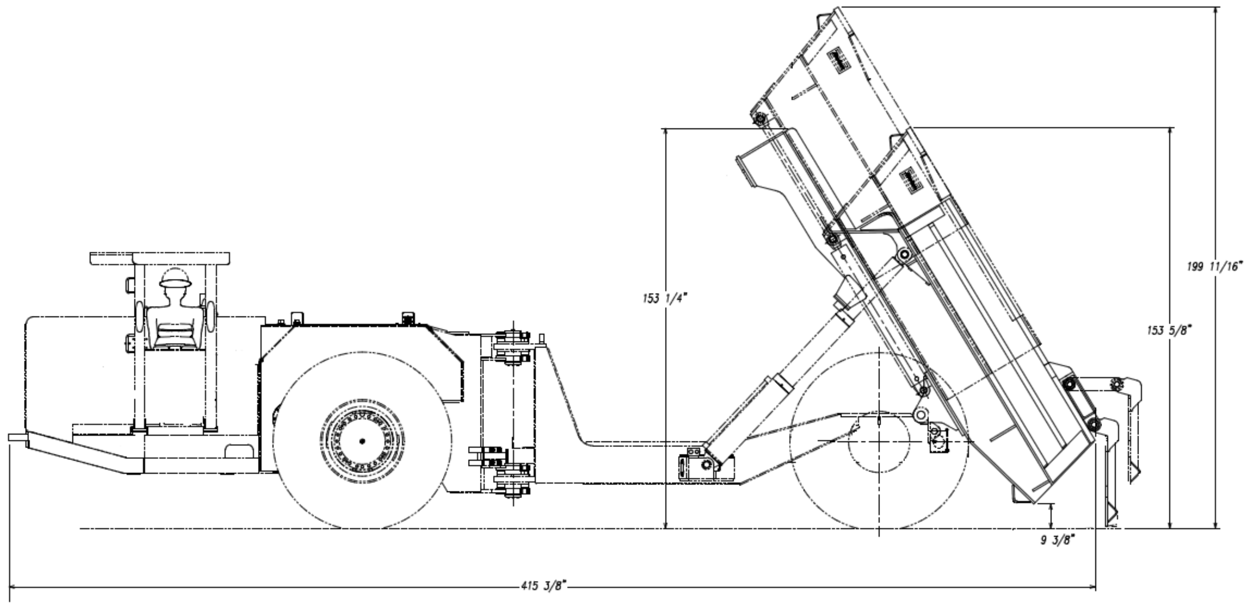


Figure 11: Two dimensional drawing of a Minetruck featuring the Teledump option. The figure also illustrates the height alternation capabilities of the box.

Unlike other products such as the Standard Box and the Ejector Box, the Teledump configuration was only available in 2D drawings and vital information such as weight of the structure, exact Payload, dumping time, etc, were not available. This meant that in order to learn more about the concept a three dimensional model of the Teledump box would have to be created.

2.5 Minetruck – New Folding Box patent

Over the years, the need for underground dumping in low ceiling mines has further driven engineers to come up with other designs that would potentially outperform the current solutions found in the market. One of those designs is the Folding Box patent that was published in 2013 by Atlas Copco Rock Drills AB. According to the patent paper, a height reduction dump system of this type would result in lower mine construction costs since less work would need to be done in the mine. [Atlas Copco Rock Drills AB, 2014] According to information received from the Marketing department of Atlas Copco Rock Drills AB, customers suggest that cost of creating a special dump station in a regular underground mine is great and the task can take up to a week.

The idea of the Folding Box patent is based on the typical Atlas Copco Minetruck vehicle with the conventional articulated platform. Its difference to a regular Box design is its ability to alter its dimension in a similar way the Teledump Box works. By considering a very general box geometry, the inventor had presented a number of possible layouts that could potentially overcome low ceiling dump issues. These layouts revolved around the idea of a divided into two parts Box structure, with the front part being described as the half facing the front section of the vehicle and the rear part described as the section facing the rear side of the vehicle. The front and rear parts of the box were imaged as being connected with a hinge system. This hinge would enable the front section to be tilted in respect to the rear section creating a folding function. Once the two sections would be folded together, the overall volume of the box would be reduced. The following Figures, Figure 12 & 13 illustrate simple sketches of the concept and its unique dumping function.

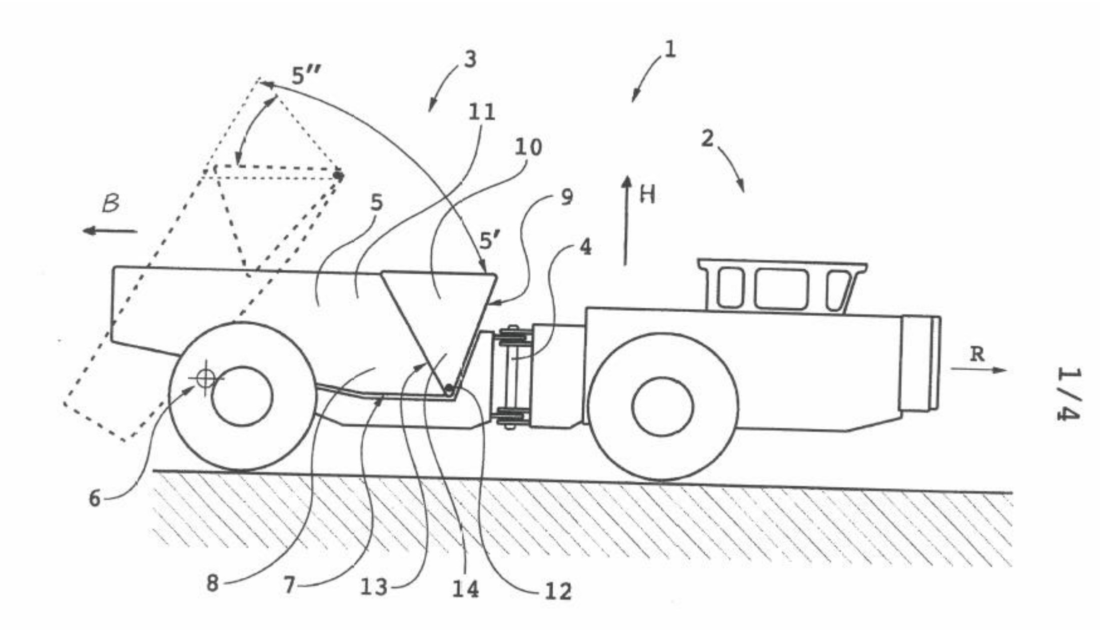


Figure 12: A side view of the Folding Box patent layout in its resting position. (Reference 6): Standard pivot location (Reference 12): Secondary pivot point location. [Atlas CopcoRock Drills AB, 2014]

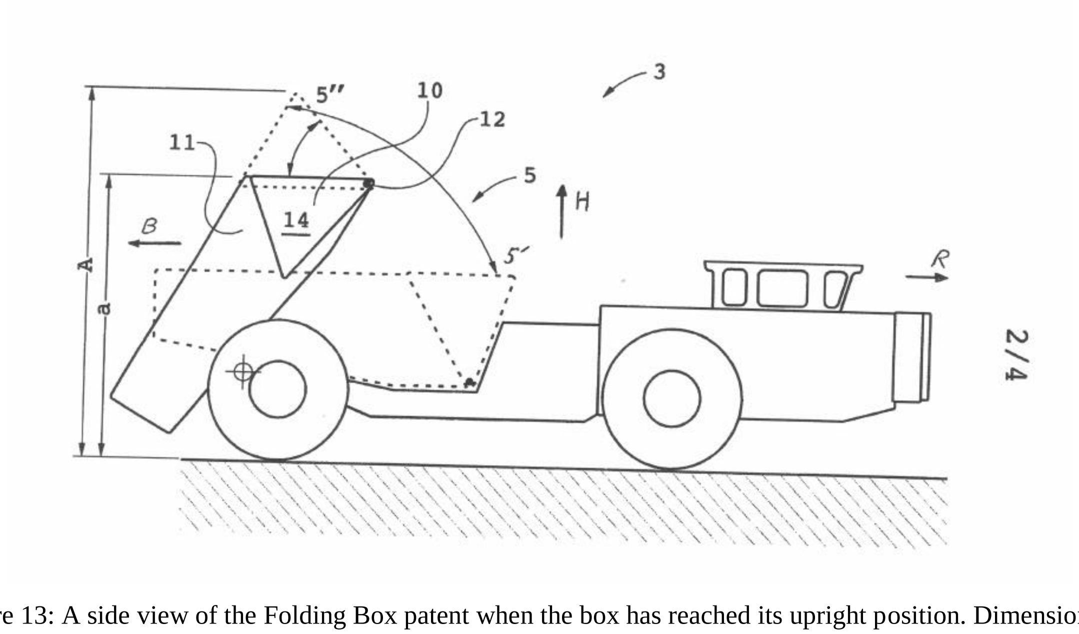


Figure 13: A side view of the Folding Box patent when the box has reached its upright position. Dimension (A) shows the height of the box when not folded. Dimension (a) shows the height of the box when folded with the aid of the pivot point (Reference 12). [Atlas CopcoRock Drills AB, 2014]

Similar to the already described hinge location, Figure 14, illustrates an alternative pivot point on the box area that appears to give a better ceiling clearance since it allows for a larger portion of the receptacle to fold.

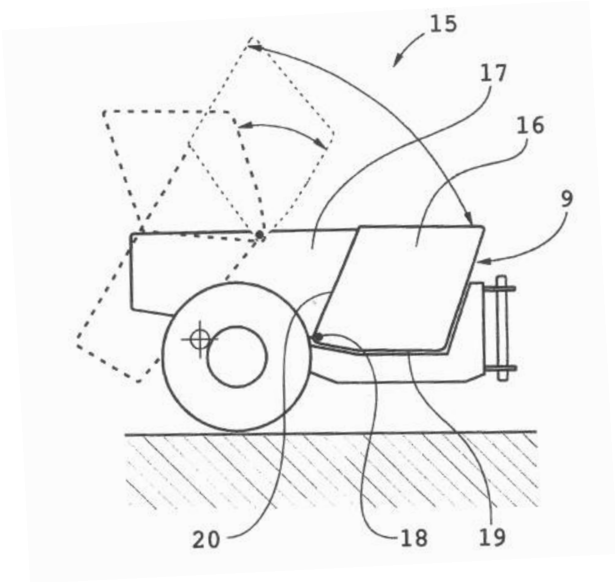


Figure 14: A side view of an alternative hinge location proposal, located at the middle section of the box, allowing for a larger ceiling clearance. This hinge location is marked with (Number 18). [Atlas CopcoRock Drills AB, 2014]

According to the official patent paper, the aid of the swing else described as folding movement, could potentially be executed in a number of different ways varying from actuators driven by an electrical system and fluid rotation actuators to gravity and/or other mechanical methods [Atlas Copco Rock Drills AB, 2014]. Following Figure 15 presents a number of configurations and aids as imagined by the patent inventor.

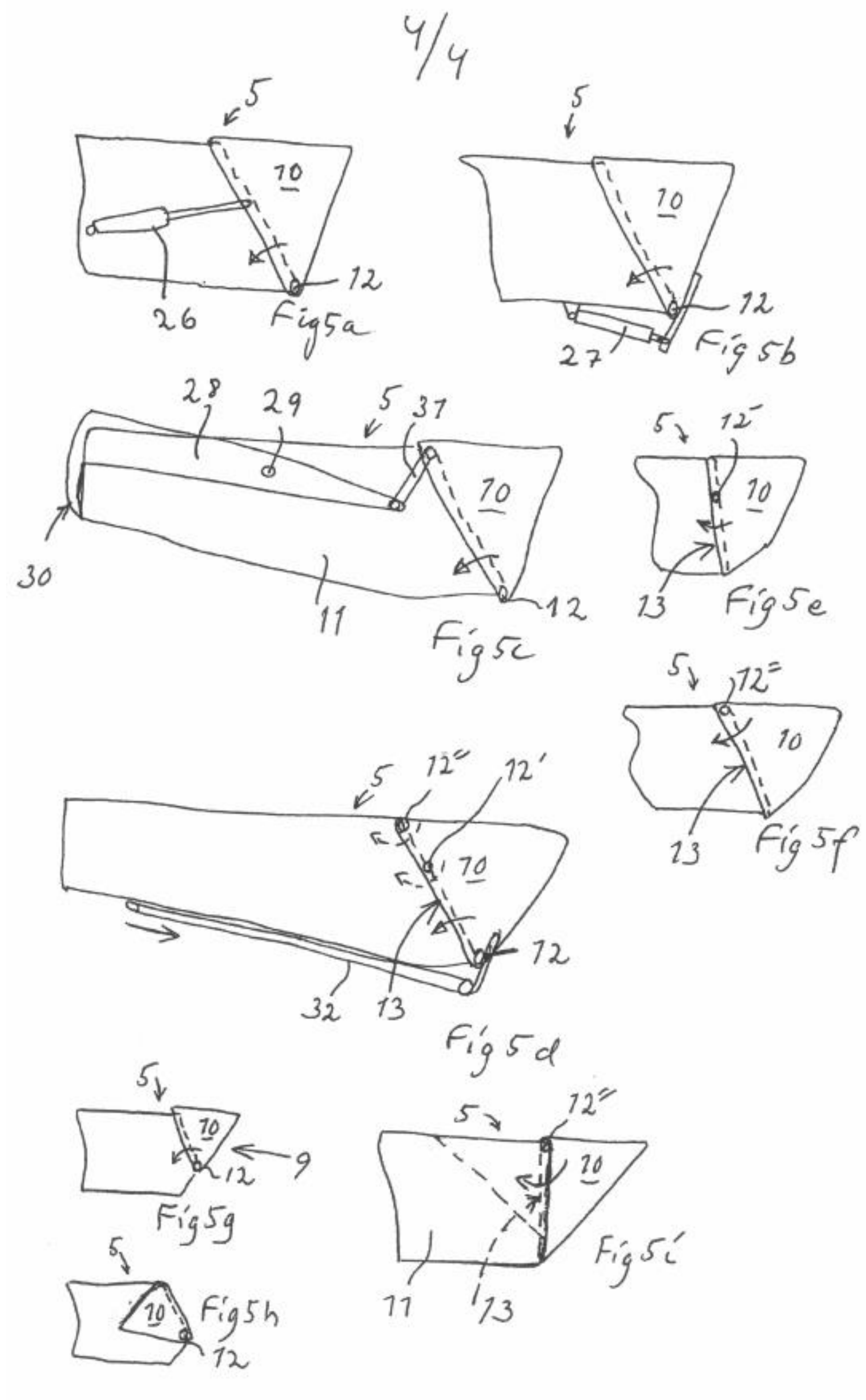


Figure 15: A number of different layout and folding aid proposals as described by the Atlas Copco folding patent inventor. [Atlas CopcoRock Drills AB, 2014]

2.5.1 Design requirements and Customer demands

Designing a box system for Heavy Duty applications such as mining is a task that requires a good engineering knowledge and experience. As explained in earlier stages of this report, the main task of this Master Thesis was to translate the two dimensional sketches of a given patent to a three dimensional model and then compare it to the current range of Minetruck options. However, it was soon evident that among the different designs and layouts a fair comparison based on the most important design and performance parameters would have to be assessed. In order to decide on the most important comparison criteria a series of discussions begun with the Design as well as the Marketing departments of Atlas Copco Rock Drills AB.

The final framework created included a series of important design parameters and customer demands based on which the design of the new concept would be assessed:

SAFETY

As with all heavy duty machinery, the most important aspect is safety. During the material handling phase of mining, multiple tons of disintegrated rock are transported across the narrow mine paths with the aid of the large Minetruck vehicles. Under these conditions, any kind of design fault can be proven to be hazardous not only for the operator of the vehicle but also for the people around it. The box design should be structurally safe when fully loaded and in case of a collision with another vehicle. Last but not least, the structure of box should not feature any exposed components that could put people standing around the vehicle in danger.

DUMPING HEIGHT

The dumping Height is the number one performance figure that was considered as it would have a direct reflection on the final verdict of the feasibility study. Being able to dump the material transported in less than 4 meters of height is the key for performing low ceiling operations underground such as backfilling. Having a concept that would be able to do such thing would directly increase its chances of being further developed for future production.

STRUCTURE WEIGHT

Structure weight is another very critical parameter that needs to be considered when designing a vehicle for a material handling application. A general rule is that the more weight added to the structure, the less ore will be transported.

PRODUCT USABILITY

The new concept shall be able to take part in all material handling applications required for the completion of a mining cycle. The three main applications where a Minetruck with low ceiling dump characteristics is often used are the following:

a. Drive in narrow mine tunnels, transporting the disintegrated material. The tunnel size on which a Minetruck vehicle should be able to operate is 4 meters in height by 4.5 meters in width. The size of the disintegrated rock can vary according to the type or blast conditions and can be anything from a small stone up to a large rock.
b. Be able to dump the blasted rock to the pre-selected dumping sites (crusher) with high ceiling facilities.
c. Be able to perform a backfill operation in a low ceiling height environment, by dumping crushed rock with no value back to the old mining tunnels. All mining tunnels are considered to have a dimension of 4.5 meters in width to 4 meters in height. In a backfill operation, the material should exit from the rear side of the box and no side tipping methods can be applied.

STRUCTURAL INTEGRITY

Structural integrity is one of the most vital parameters when it comes to designing a new box unit. A new Folding Box should be able to pass through two basic assessments:

a. Normal Operation Loading Case: Simulation of a loading condition on which the box is fully loaded with ore while driving through a mine tunnel with a rough terrain.

b. Side Collision Loading Case: This FEA assessment is based on a side collision scenario on which a large loader hits the side of the box while taking part in the material handling process. The results observed during this test can also determine the feasibility of a new concept and suggest for further improvements or re-enforcements on its structure.

COST

Cost also an important parameter that can determine if a new concept can be a feasible or not. Keeping the development and production costs low, by introducing a reasonable box layout is a key for the successful completion of the project.

3. THE DESIGN PROCESS

This chapter presents the working process followed for the completion of this Master Thesis Feasibility study. The first part of the design process was to translate the 2D drawings of the Atlas Copco Teledump configuration into a 3D model. The second part was to plan and design a number of concepts for the realization of the Folding Box patent.

3.1 Investigating the Teledump Box

The study of the various Atlas Copco Box designs was a very helpful and interesting step towards the further understanding of the Minetruck vehicles. One of the most promising and interesting designs was the Teledump Box configuration that was initially launched for the Canadian market.

However, due to the fact that a three dimensional model of the Teledump Box was not available, important information about its design characteristics such as structure weight, ore capacity and box volume were missing. Due to this issue, the idea of creating a simplified CAD model out of the original drawings was born. The simplified CAD model was decided to be made out of the following sections. In order to save time, these sections were modeled as single parts. These parts are listed below:

- Front Section of the Teledump Box
- Rear Section of the Teledump Box
- Secondary Chassis / Frame
- Tail Gate
- Tail Gate arms

Once the parts mentioned above were ready, they were be assembled on a standard Minetruck Chassis and constrained in order to be able to replicate the Teledump function. Since the time for the Master Thesis project was limited the design task was undertaken by external designers while supervised by the Atlas Copco office at Orebro. The three dimensional modeling of the whole concept took some time to complete and the final result is shown in Figures16, 17 & 18:

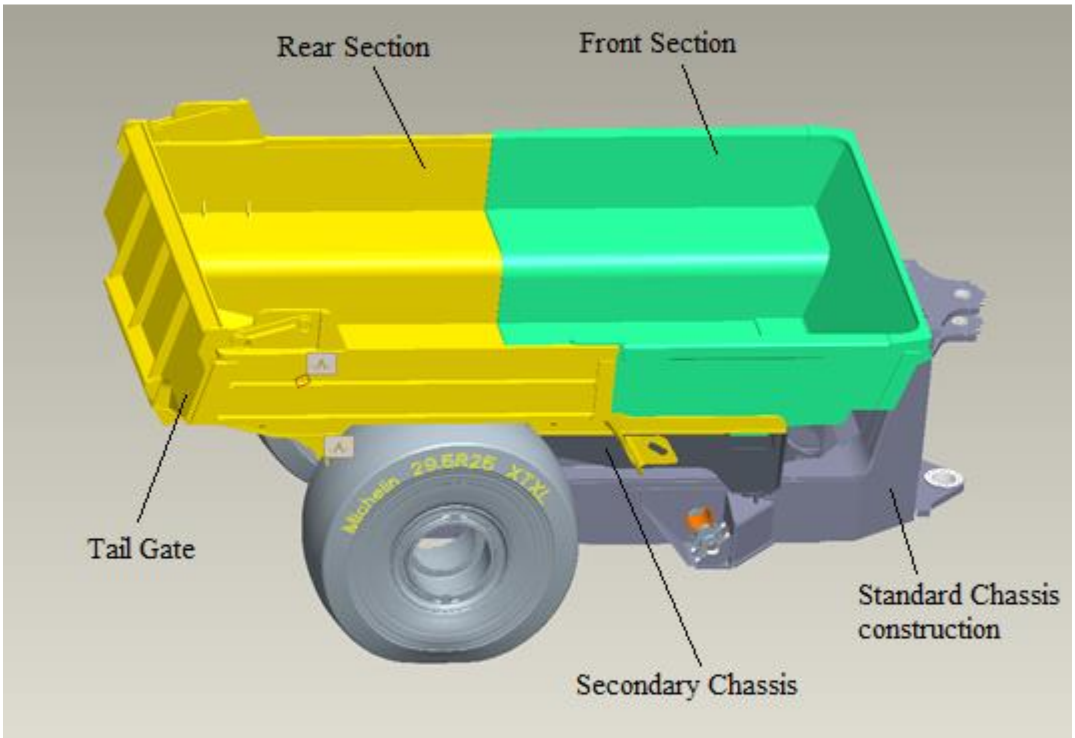


Figure 16: The complete assembly of the Teledump concept once installed on a Standard Minetruck chassis

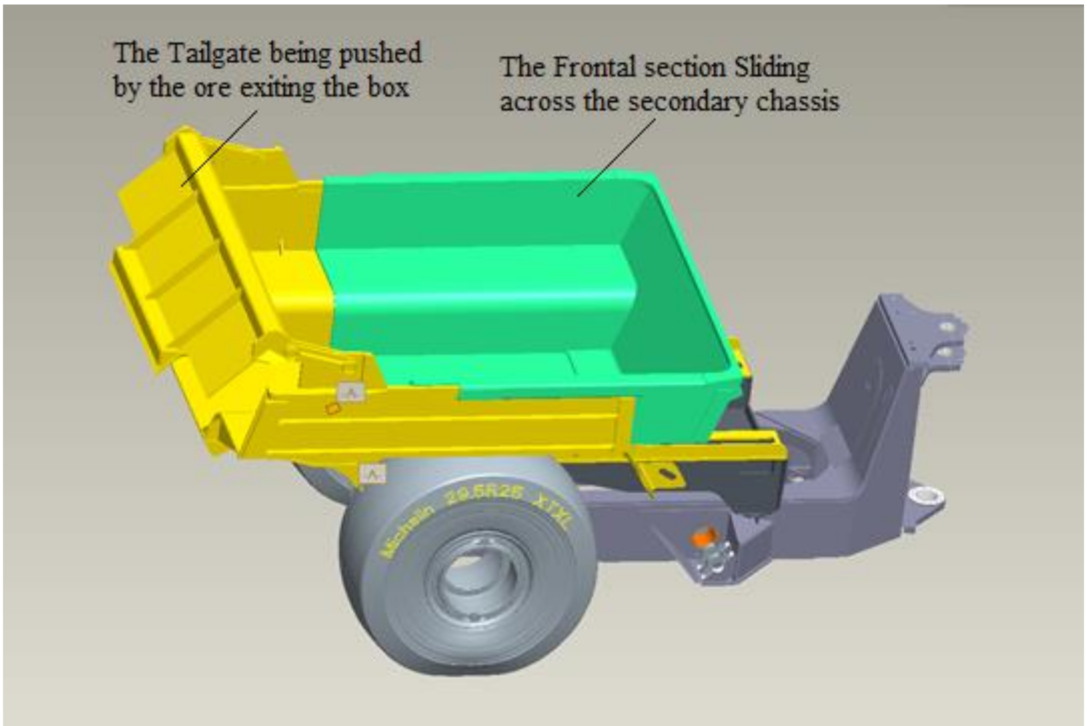


Figure 17: The first stage of the dumping process – retraction of the font box section

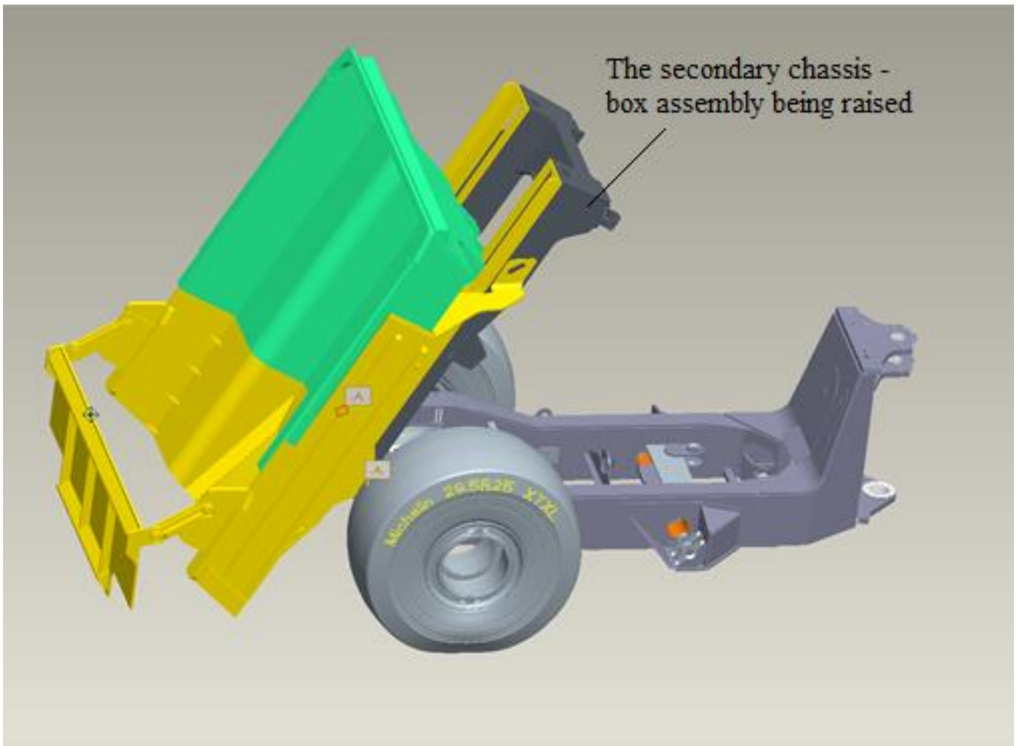


Figure 18: The final stage of the dumping process – The box structure and secondary chassis being raised.

Having a complete three dimensional model, the collection of useful information about the Teledump product was an easy task. By carefully studying each part of the box, the following specifications were documented. Perhaps one of the most important specification values that we were interested in observing was the rear axle loading data. By creating an ore volume based on the standards followed by Atlas Copco Rock Drills AB and considering the center of gravity, the data was revealed. The use of a standard Minetruck chassis meant that the rear axle design was going to be identical to the Standard and Ejector Box axles. The following table, Table 3 includes all vital specification values related for the Teledump Box configuration.

Table 3: The most important performance specifications documented for the case of the Teledump Box configuration.

Parameter	Units	Value
Ore Density	[1000kg/m^3]	2.2
Volume of Ore Transported	m^3	15.3
Payload	Tons (t)	35.5
Structure Width	mm	3050
Dump Height	mm	3895
Structure Weight*	kg	8200
Dump Cycle Time (est.)	sec	35
Payload / Structure Weight	Ratio	4.3

*Note: *The value of structure weight includes the two Box sections, pivots, and Hydraulic cylinders. The Chassis frame, rear Wheels and axle were not considered.*

3.2 Investigating the Folding Box Concept

When introduced to the Folding Box patent, the information available was only a description of the concept on paper and a number of hand drawn sketches based on a general box shape. In order to proceed to a concept realization and deliver a design proposal, a number of steps had to be completed. The first step was to go through the patent paper and collect all information data regarding the different layouts of the box before selecting the most appropriate for the Minetruck case. The fact that all layouts were simply drawn by hand meant that more detailed models would have to be designed in order to fully observe the function of the folding box idea. In theory the design layouts and box shapes that could potentially be followed were unlimited. However, in order to frame the project, the following decisions were taken:

- The new design was based on the patent paper description.
- The general box geometry selected was based on the Standard Box design. The model was split in half and some of its sections were modified.
- The new box's inner section was also based on a similar to the standard box pattern for an optimal ore flow.
- For compatibility reasons, the new Folding Box was placed onto the current range Minetruck Chassis.
- The new concept's overall dimensions were carefully selected. The width of the Box which is the most critical of dimensions (due to the narrow mine tunnels) was kept as 3050mm in order to match the Standard, Ejector and Teledump Boxes.

With this framework in mind, the concept generation phase begun.

3.2.1 Folding Box – Concept Generation

The concept generation phase, begun with a small study around the geometry features of the Standard Box and the exploration of the possible sections that if modified could allow for a folding action. What was already known about the new concept was the fact that in order to create its prototype in CAD, the standard box had to be divided in two sections, front and rear and then joined together by a hinge.

When designed few years ago, the geometry and overall shape of the Standard Box had been determined considering factors such as optimal ore flow, structural rigidity and weight distribution. Furthermore, the large size rear tires and hydraulic cylinders have also had an influence to the overall shape of the inner box section. The above mentioned factors resulted in a box geometry featuring very few sections that could be modified to accommodate a folding system.

The following figure, Figure 19, illustrates two sections of a Standard Box that could potentially be divided. The first of the two mentioned sections is located at the front wall of the box unit. The reason this area was considered was that it has been made out of a single, straight sheet metal and therefore it would be relatively easy to split.

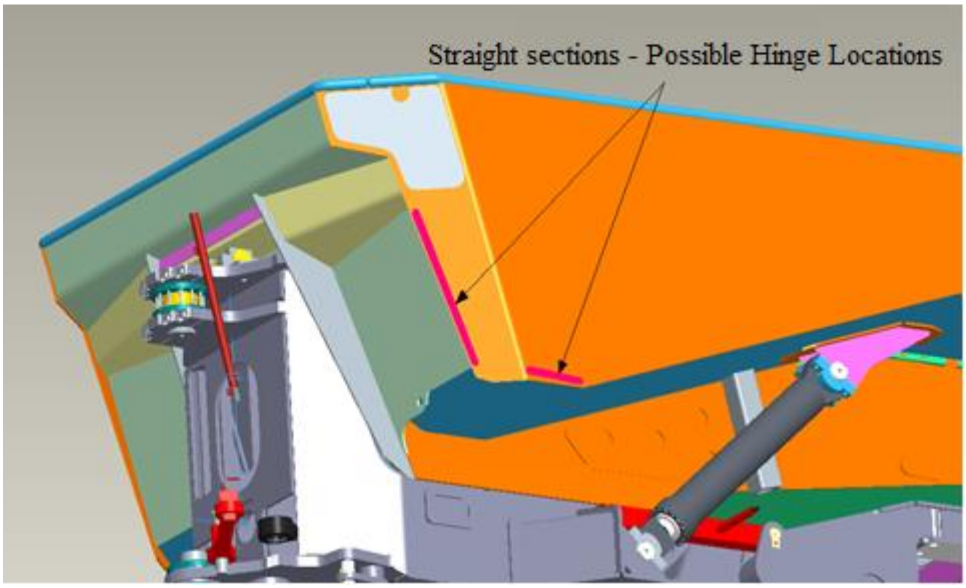


Figure 19: A general view of the standard box mounted onto the chassis, the sections highlighted illustrate possible areas where a hinge could be places to allow for the folding of the frontal section.

The second section considered was at the bottom part of the box, right before the start of the large wheel arches that house the hydraulic cylinders and wheels of the Minetruck vehicle. This is a section that is not completely straight all across, meaning that there is a small step along the bottom side, as illustrated in Figure 20 below. For a long hinge to be placed across the bottom of the box, the step had to be modified into a straight section.

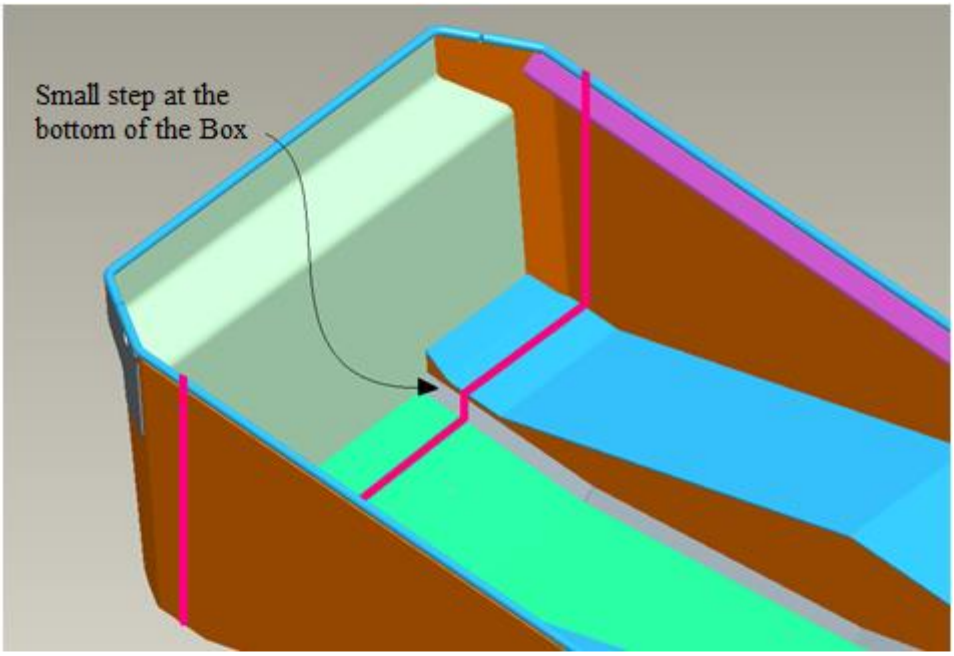


Figure 20: Imaginary line of how the receptacle system could be divided to allow for a folding function. The small step across the bottom would have to be converted to a straight section in order for a continuous hinge system to be fitted.

Based on the above observations, two different Folding Box concepts were generated. The difference of these two concepts was at the hinge location and the way they were divided. Having two different alternatives for the folding solution was believed to be a very good approach for reaching to an optimal design solution.

A. CONCEPT 1 - PLACING THE HINGE HIGH

This concept was based on the idea of dividing the box into two parts, front and rear, with the split being made on the font part of the wall. Figure 21 illustrates a side view of the front and rear box sections completing the overall structure and how they were joined together for the formation of a single box. The purpose of highlighting part of the rear section in yellow was to show that this part of the box would have to be narrower to allow for the front section (marked in blue) to slide across it and replicate a folding action.

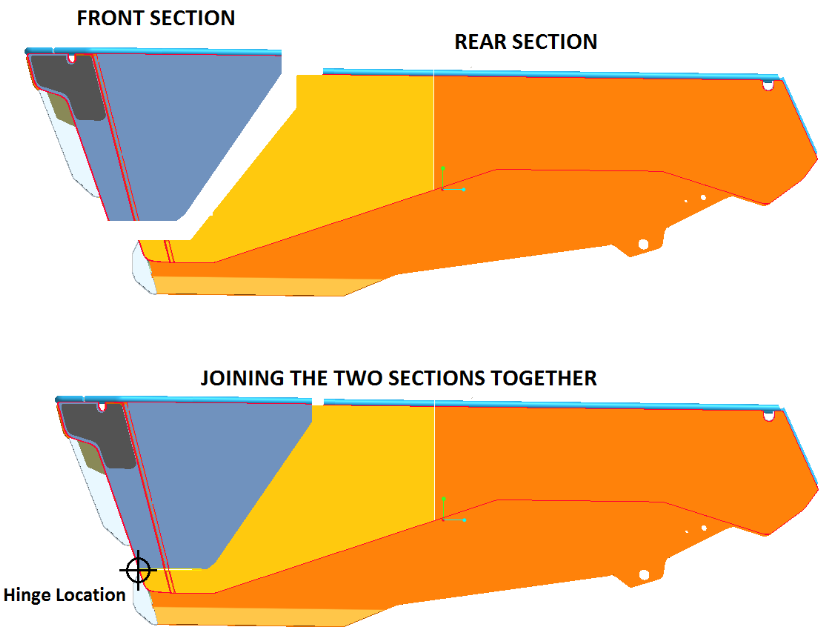


Figure 21: Side view of the front and rear sections forming the Folding Box Concept 1

By looking at this concept, the first assumptions that were made were the following:

- By placing the hinge high on the box structure, the overall size reduction was not going to be as effective as by introducing a hinge on the lower part of the box.
- The hinge location of this concept leaves the bottom part of the rear box section intact. This section was potentially going to add some strength to the rear section by keeping the side walls joined together.

B. CONCEPT 2 - PLACING THE HINGE LOW

This concept was again based on the idea of dividing the box into two parts, front and rear. However, on this concept the split was made at the bottom part of the box. Figure 22, illustrates a side view of the front and rear box sections completing the overall structure and how they were joined together for the formation of a single box. Again, the purpose of highlighting part of the rear section in yellow was to show that it was narrow to allow for the front section to slide across creating a folding action.

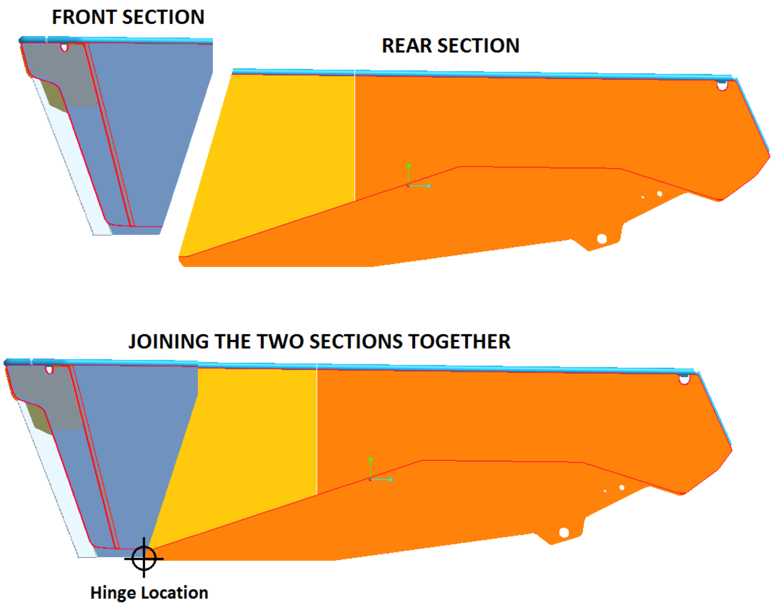


Figure 22: Side view of the front and rear sections forming the Folding Box Concept 1

By looking at Concept 2, the first assumptions made were the following:

- By placing the hinge lower on the box structure, the overall size reduction was potentially going to be larger due to the fact that a bigger portion of the box would be folded away.
- By getting rid of the rear section's bottom part, the potential structural issues would be increased. This assumption was based on the fact that there would be no structure holding the right and left walls in place.

3.2.2 Folding Box – Three Dimensional Design

Once a number of hand drawn sketches and plans were made for both Concept 1 &2, it was time to translate them into a three dimensional CAD model. Again, due to lack of time, the assignment of the three dimensional CAD modeling was delivered by external designers and supervised via Atlas Copco at Orebro. The directions given towards the completion of the models were the following:

- Use of the standard box design as a platform for the geometry of Concept 1 & 2.
- Simplified modeling of both front and rear box sections as single parts.
- No need for the illustration of a hinge model.
- Installation of Concept 1 & 2 boxes onto the standard Minetruck chassis.

A. CONCEPT 1 – PLACING THE HINGE HIGH

Following, Figures 23, 24 & 25 illustrate the completed CAD model of Concept 1 as received from the external designer team. The model included the front and rear sections of a box hinged together and assembled on a standard chassis. The given constrains, allowed the box to be lifted and folded according to the patent description.

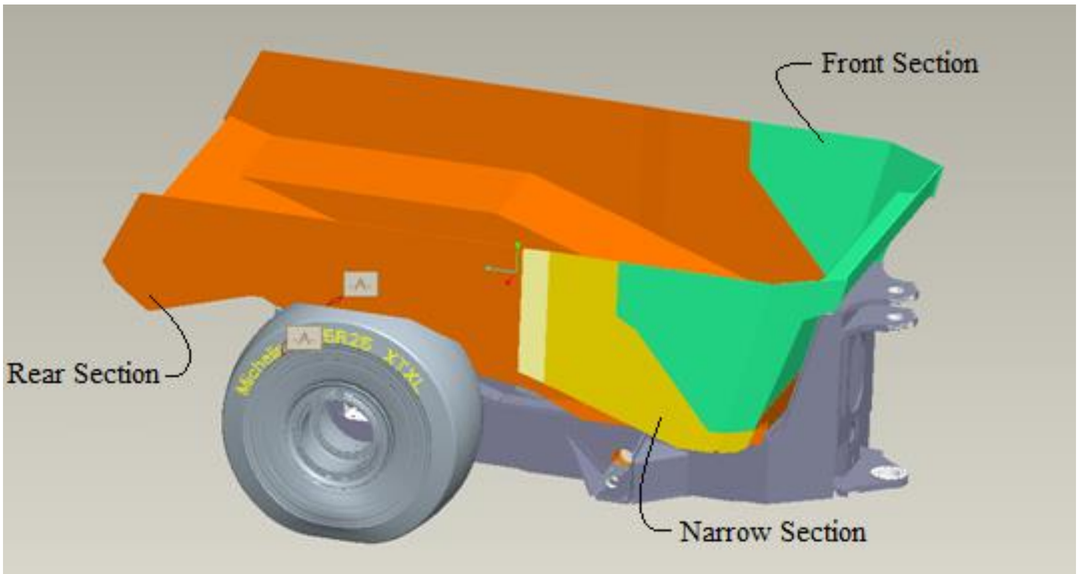


Figure 23: The overall assembly of Concept 1 with the hinge location high on the front part of the box. The yellow area represents the narrowest box section and the green the front part of the box.

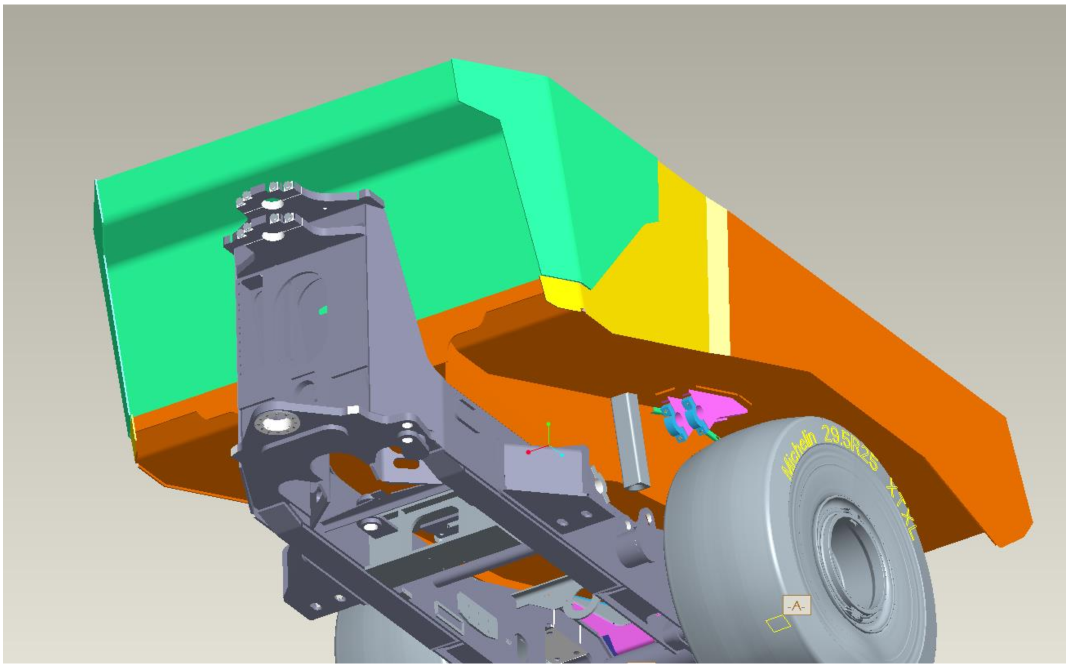


Figure 24: Another view of the fully assembled Concept 1 box configuration.

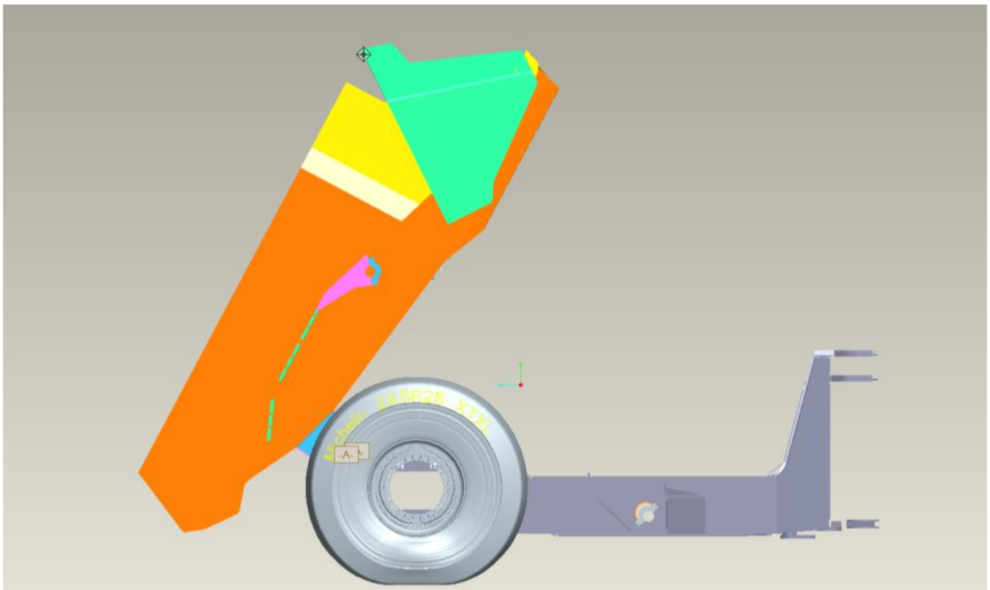


Figure 25: A side view of the folding box Concept 1. This image illustrates the upper dumping position of the box

B. CONCEPT 2 – PLACING THE HINGE LOW

Following, Figures 26, 27 & 28 illustrate the completed CAD model of Concept 2. The model included the front and rear sections of a box hinged together and assembled on a standard Minetruck chassis. The given constrains, allowed the box to be lifted and folded as described in the original patent.

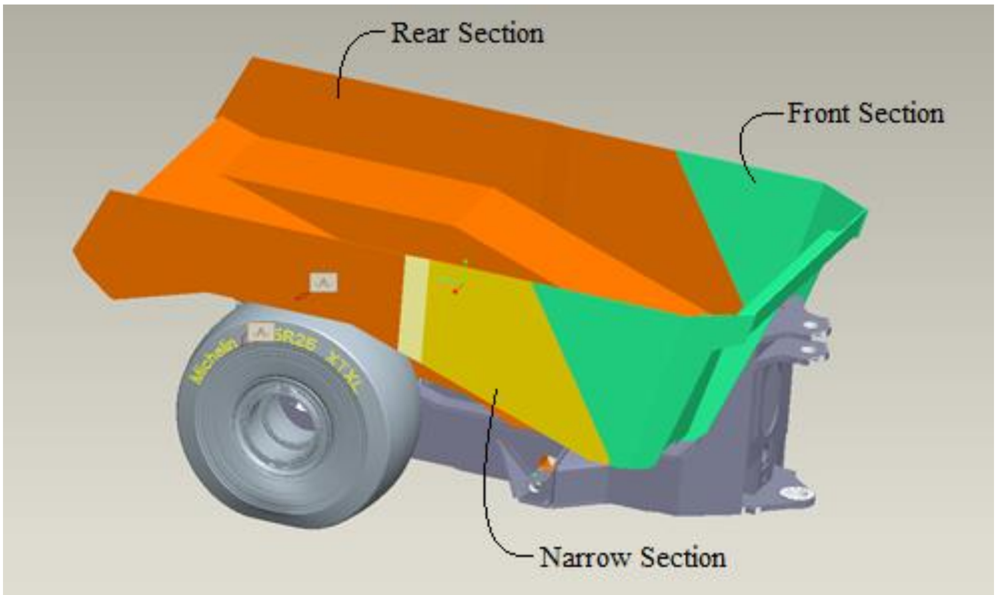
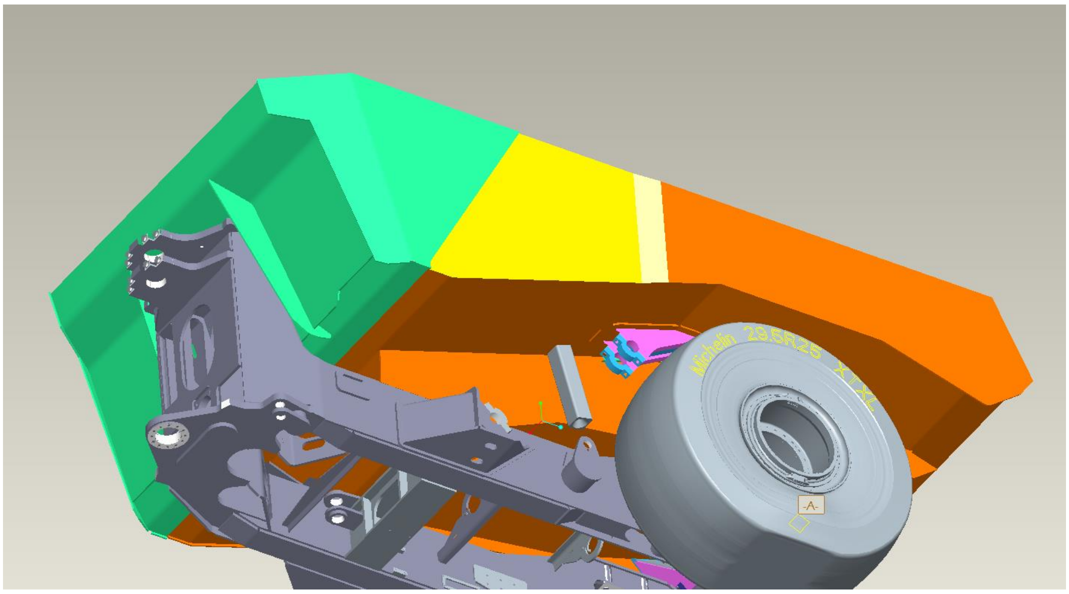


Figure 26: The overall assembly of Concept 2 with the hinge location located at the lower section between the front and rear box sections. The yellow area represents the narrowest box section and the green the front part of the box.



Figur 27: Another view of the fully assembled Concept 2 box configuration.

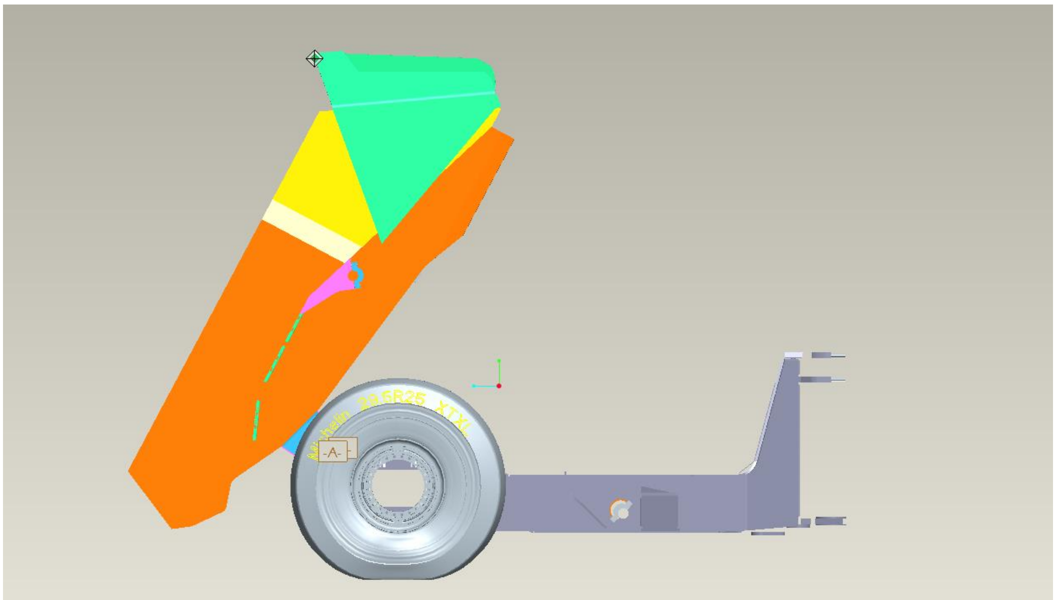


Figure 28: A side view of the folding box Concept 2. This image illustrates the upper dumping position of the box

3.2.3 Folding Box – Addition of Reinforcements

Although the CAD prototypes delivered by the external designer team were satisfying enough for the representation of a folding function and the understanding of the overall concept, there was also a need to test their structural behavior under stress and during a typical working cycle. The two conceptual models received, were missing important reinforcement components found in the standard box. These components are custom made steel plates that are welded to the main box construction to improve the box's structural integrity and increase its loading capacity. Knowing the design layout of those components and by taking under consideration the geometry of the two new layouts, a similar design approach was attempted in order to improve their structural integrity.

The plan for the reinforcement design was to apply a number of changes to the rear part of the box, since this was considered to be the most critical section in both Concept 1 and Concept 2. The first component introduced to both models, was a strengthening beam across the rear end of the rear box section. The geometry of this component was based on a similar beam design used in the rear end of the Standard box. Again for simplicity reasons, this design was modeled as a part of the rear box rather than a different component. Figure 29 illustrates the reinforcement beam modeled.

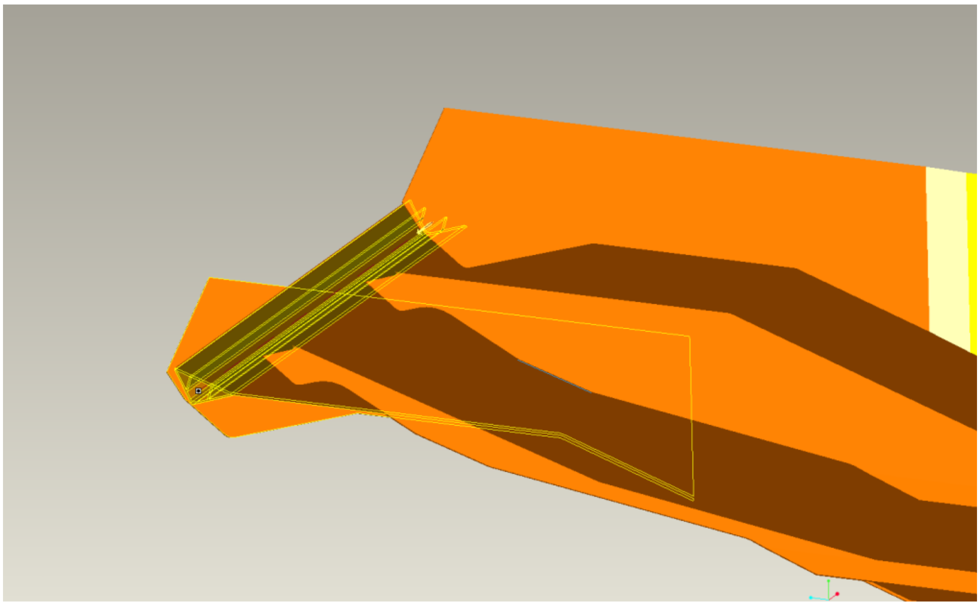


Figure 29: Marked in yellow is the 10 mm thick reinforcement beam.

The next addition to both Concept 1 and Concept 2 rear boxes was the addition of two 45 mm thick plates. Once more, the idea for this reinforcement component came from the standard box geometry. An identical geometry feature to the one shown in Figure 30 below was placed in both right and left sides of the box.

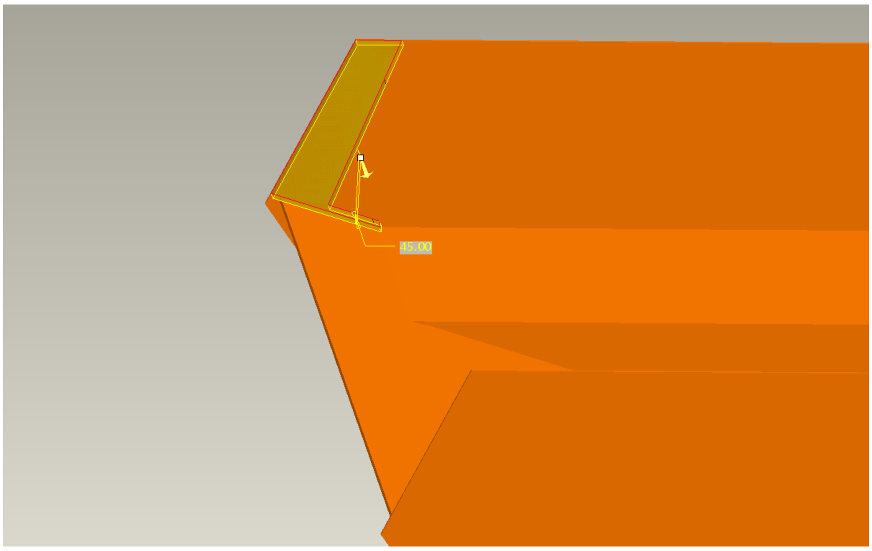


Figure 30: Marked in yellow is the additional 45mm plate that was added to reinforce the side box walls

Moving on, another important feature was added in bot Concept 1 and Concept 2. This time although the geometry pattern was identical in both models, the length of the reinforcement beam, shown in Figure 31 below, varied according to the box dimensions. Once more the idea for the long beam placed on the right and left box sides came from the Standard box layout as it was proven to be a good structural component addition in the past.

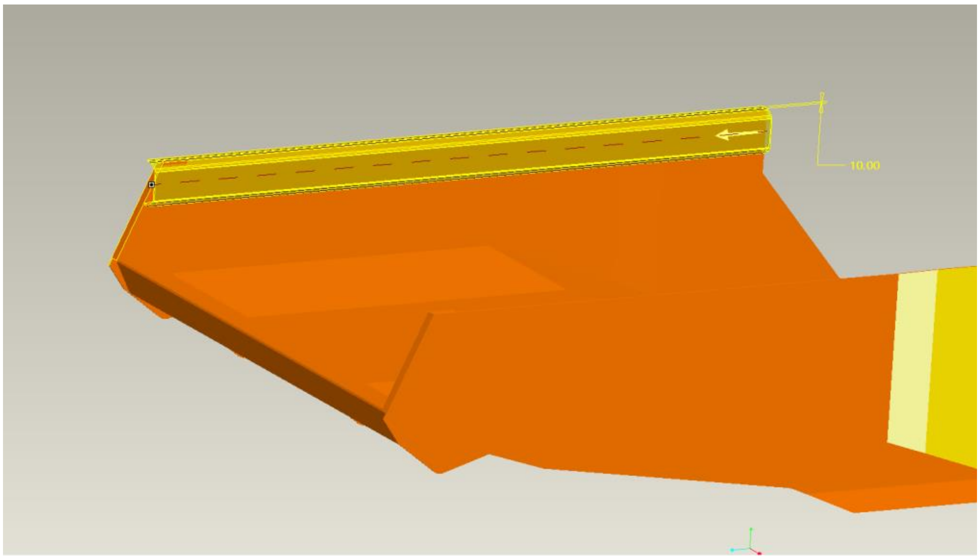


Figure 31: Marked in bright yellow is the long beam feature that was extruded across the upper box part. This figure illustrates the modification in Concept 1.

The next modification added to both models was the addition of a steel structure that represented the friction plate featured in the rear end of a standard box. Again for the modeling part, a simplified approach was followed and the original friction plate's 'cluster' pattern was not used. Figure 32 illustrates the 12mm thick friction plate addition to one of the box models.

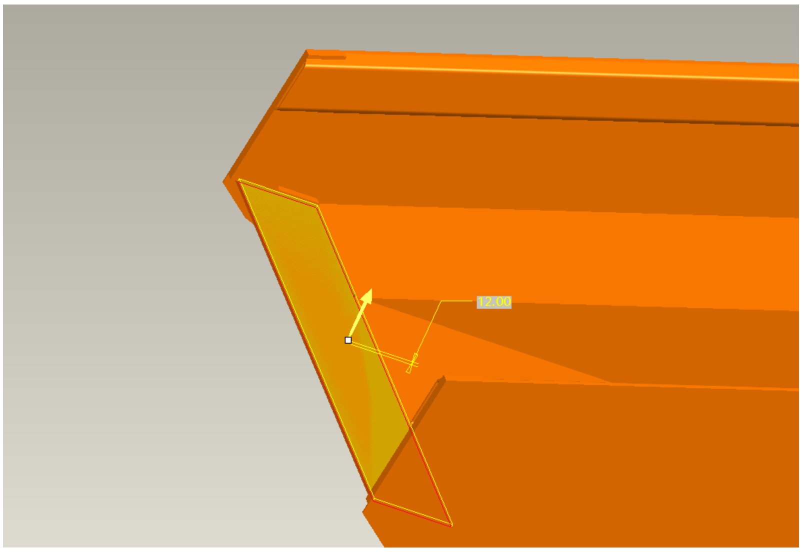


Figure 32: The extrusion of a 12mm thick friction plate at the box's rear end.

The next critical reinforcement for both Conceptual models was the introduction of additional beams that were placed once more in the inner section of the box to improve its structural properties. The beams were placed in both sides (right and left) of each box and their dimensions and position was slightly altered due to their different geometry. Figure 33 & 34 show the addition of the beams in both Concepts.

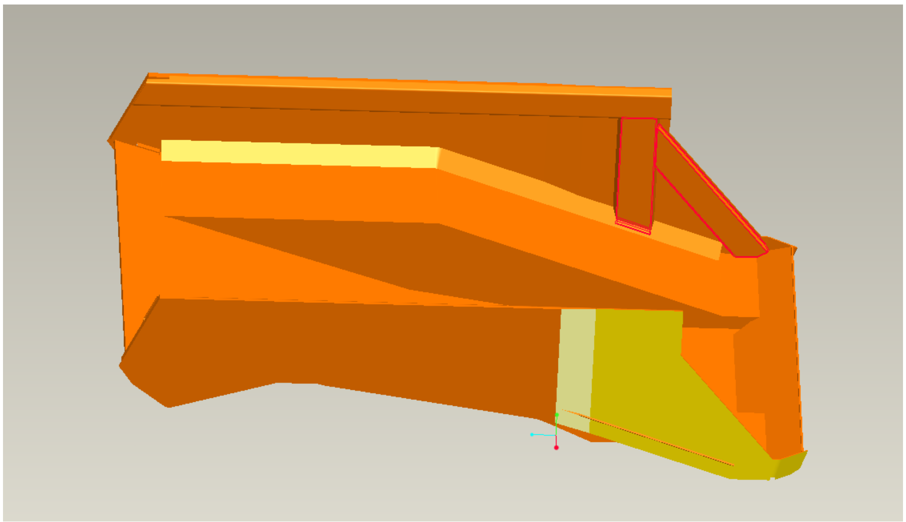


Figure 33: Illustration of the extra beams added to the rear section of Concept 1, highlighted in red color.

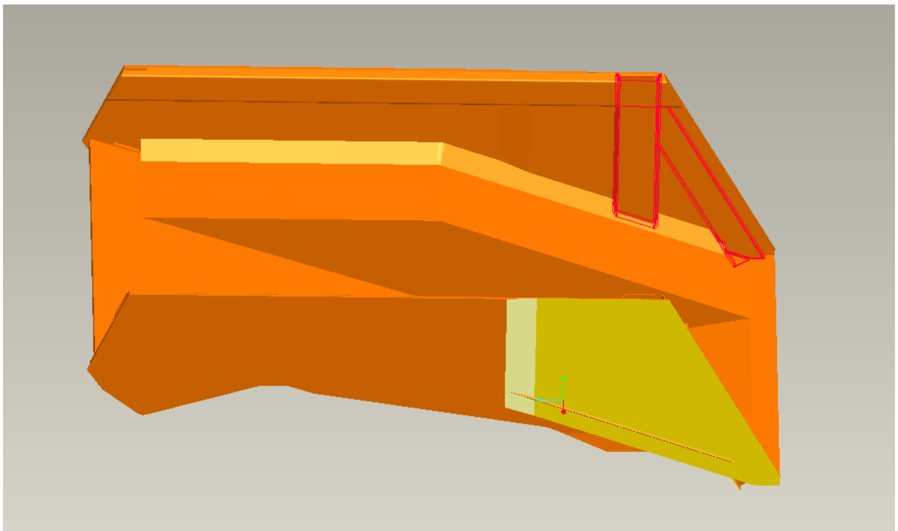


Figure 34: Illustration of the two extra beams added to the rear section of Concept 2, highlighted in red color.

The final structural addition applied in Concept 1 & 2 was a 10mm thick plate that was designed to connect the side walls to the inner wheel arch section as shown in Figure 35 & 36.

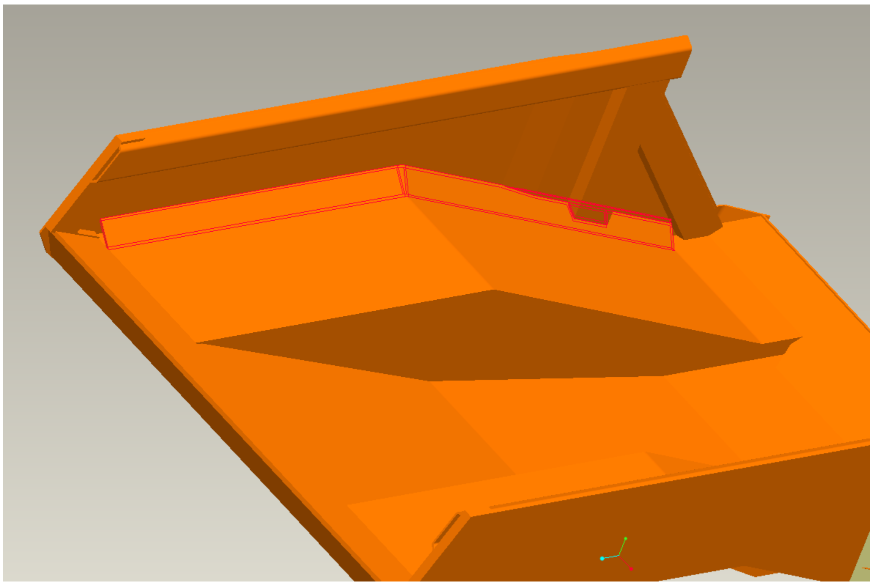


Figure 35: Concept 1 - The addition of the side wall to upper floor section reinforcement plate, marked in red color.

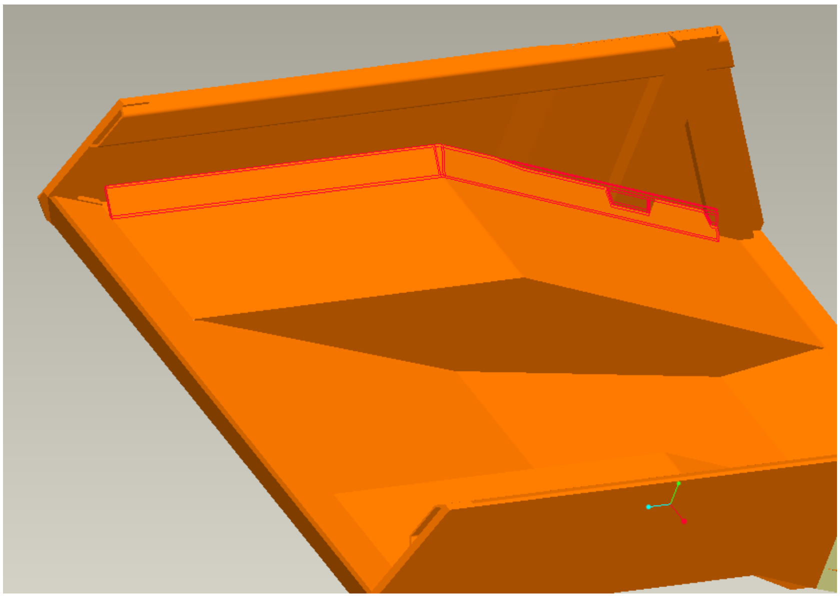


Figure 36: Concept 2 - The addition of the side wall to upper floor section reinforcement plate, marked in red color.

3.2.4 Folding Box – Study of Folding Aid Methods

The concept generation phase continued by the investigation of the most ideal folding aid methods that could be used for tilting the frontal section of the box towards the rear. Here, the term of folding aid is used to describe the system powering the folding action. As described in the patent, a number of different components and parts could potentially be implemented to undertake this task. For example, one of the proposed configurations was to introduce an electrically driven actuator assembly. In order for this system to work, a set of two electrically driven actuators could be fitted underneath the rear box section and be driven so that the force exerted would make the frontal section swing in respect to the rear. To complete the concept, a number of cylinder supports and swing arms would be added. The following Figure, Figure 37 shows a sketch of how this layout could potentially look like. The layout was designed in a two dimensional sketch program and is only used as a visual representation of the idea. The concept illustrated in this example is Concept 1 with the upper hinge location.

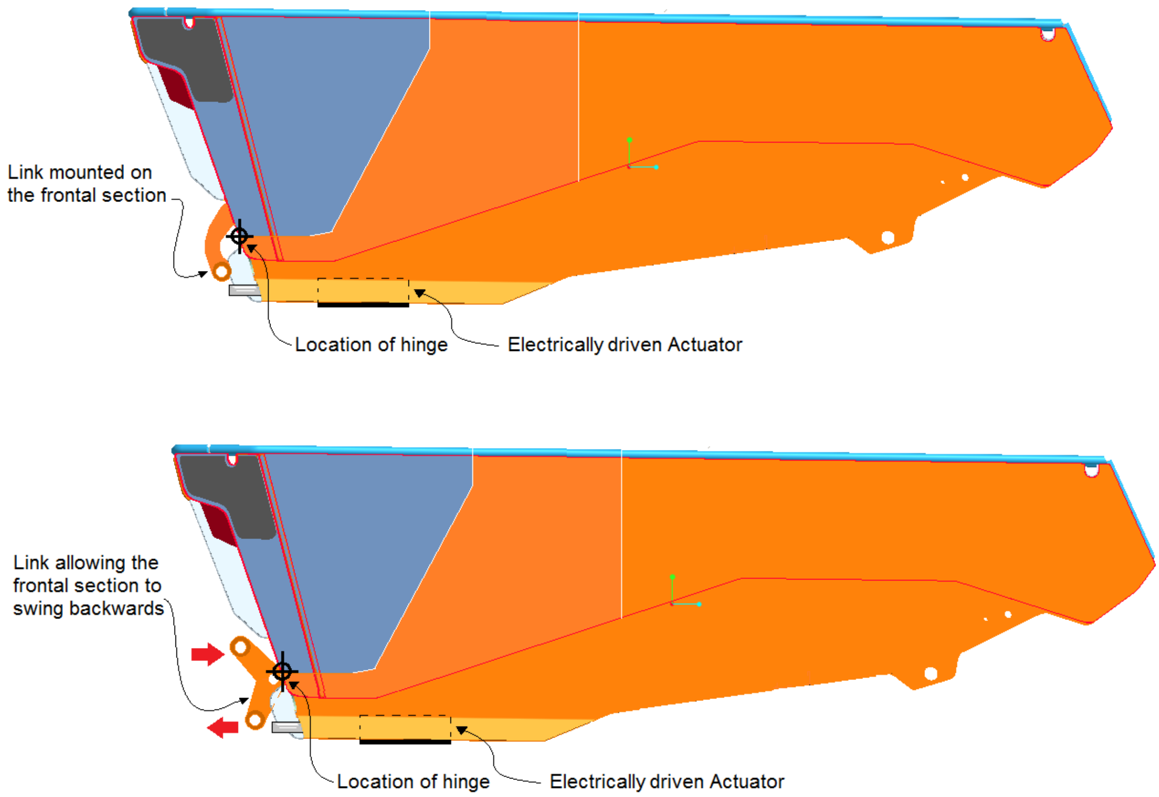


Figure 37: Two proposed configurations for the addition of an electrically driven actuator system that could be used in order to fold the front part of the box. In this example the configurations are based on the Concept 1 model.

Another alternative would be to make use of a link system that would automatically fold the frontal section of the box while the whole box would be lifted by the primary hydraulic cylinders. In a similar way, a folding motion could be potentially triggered with the link to a hydraulically operated tail gate. As the tail gate would open, the external links connected to the front side of the box would force it to fold towards the rear end. Similar mechanical aids and links have been designed by Atlas Copco and fitted in various Minetruck box systems in the past and therefore they would be easy to tackle in this project. However the fact that the sequence on which parts move cannot be altered makes this a not very flexible system. In addition, external connections and links mounted on the outer side of the box can easily be damaged by large size rocks or another mining vehicle and even be blocked by small sized ore. Another disadvantage to this alternative is the weight addition. External links for Minetruck applications tend to be large and heavy. With all this information in mind, the idea was abandoned in an early stage.

Another suggestion mentioned by the patent inventor was to get rid of all mechanical folding aids and let the gravitational force take care of the folding action. The idea is that once the box would start lifting with the help of the primary lifting cylinders, the front part of the box would eventually fold while being forced by gravity. This according to the patent inventor could simplify the overall design as fewer components would be required. A simple sketch of what this modification could look like is illustrated in the figure bellow, Figure 38.

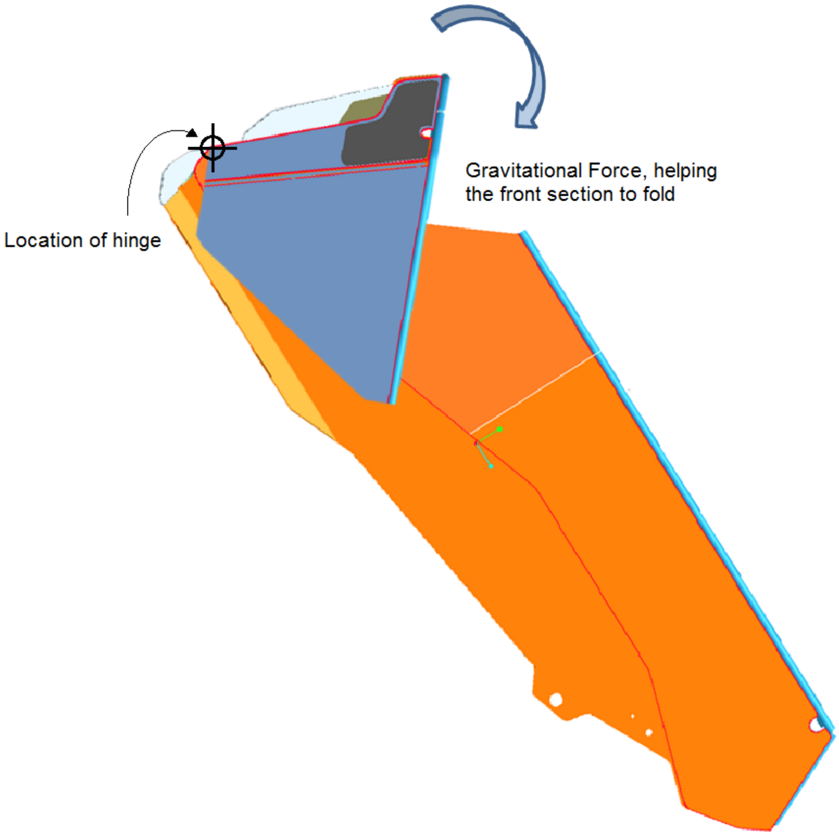


Figure 38: Making use of the gravitational force to complete the task of folding. Once more, Concept 1 layout was used for the graphical representation of this idea.

Although it might sound like a good idea, there are a number of drawbacks in such modification. First of all, there might be many complications in bringing the front section back to its initial position. If properly made, the return of the frontal part to its resting position could be attained with the help of gravity. However, in order to prove that this would work, extensive tests would have to be planned and executed prior to production. Second, in a real case scenario, the density and humidity of ore varies and along with this, the angle on which ore starts flowing outside the box. This could somehow affect the angle on which the frontal section would be folded in each case, resulting in further complications.

The last folding aid concept explored, involved the addition of a secondary set of cylinders operating with hydraulic fluid. The way this would operate is almost identical to the electrically driven actuators presented but instead of adding a new electrical system, the already existing hydraulic system would be modified to feature a second cylinder set. Figure 39 illustrates a rough representation of two different hydraulic cylinder aid layouts.

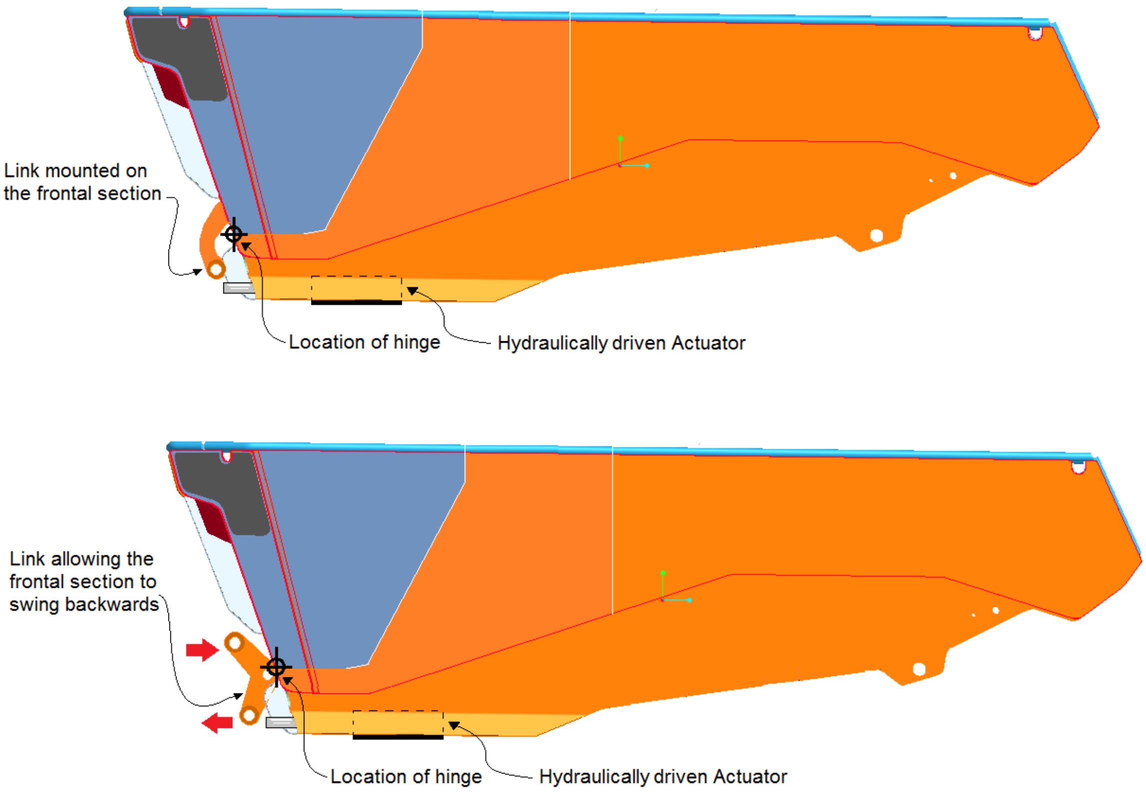


Figure 39: Two proposed configurations for the addition of a secondary set of hydraulic driven actuators that could be used in order to fold the frontal side of the box. Once more, a 2D sketch of Concept 1 layout was used for the graphical representation of this idea.

By analyzing all information gathered, the final solution was decided to be based on a hydraulically driven actuator system. A system as such, poses a number of advantages compared to the other concepts. Hydraulic actuator systems are widely used in trucks of all kinds and can also be found in all Atlas Copco Minetruck products. The reason is that they offer optimal performance in high force applications as the one described [mbtmag, 2014]. Furthermore, all Minetruck vehicles already feature a hydraulic system used for operations such as steering and tilting the receptacle. By fitting electrical instead of hydraulic actuators for the folding function, the required addition of electronic systems to operate them would potentially increase the complexity and cost of the end product.

3.2.5 Folding Box – Study & Design of Hydraulic cylinders

The initial study of the various folding aids showed that the most logic approach was the introduction of a hydraulic cylinder set. The task of designing and sizing the cylinders for this specific application came with a number of unknown factors. These factors are presented in the form of steps below:

- **Step 1:** First of all, in order to design a set of hydraulic cylinders, their position within the model and the piston stroke required was found. By finding the actual mounting position and stroke required for the folding action, the design phase came one step closer to its completion.
- **Step 2:** Another unknown factor was the operational sequence based on which the box would complete its working cycle. By studying the patent, it was obvious that the folding action of the front section had to be completed prior to the box reaching its upper

position. However, the time on which the folding action would be initiated had to be determined based on factors such as box geometry, ore flow and cylinder size and specification. These questions triggered a small study on ore flow based on previous experiments.

- **Step 3:** Next, the force required from the cylinders to fold the box's front section was estimated based on assumptions made from studying the ore flow and the amount of ore present in the box at the given moment.
- **Step 4:** Next, by considering the available hydraulic pressure from the Minetruck hydraulic system and the type of application, the final dimensions of the hydraulic cylinders were found. Once all important dimensions were available, a simple CAD model of a cylinder pair to be featured in the final design proposal was made.

With the current design still being in a conceptual stage, the aim of this small study was to get a working concept and to see what kind of assumptions and calculations would have to be made for this to work in the future.

Step 1:

The first action taken was the development of a simple two dimensional drawing of a Folding box in a CAD environment. This drawing featured the very basic parts of a Folding Box configuration and it was made in such way that it could replicate its operation. By introducing a simple cylinder sketch on the drawing and folding the box, an approximate stroke number was measured. Figure 40 illustrates the two dimensional drawing as created in the CAD software in its resting position of angle 0º.

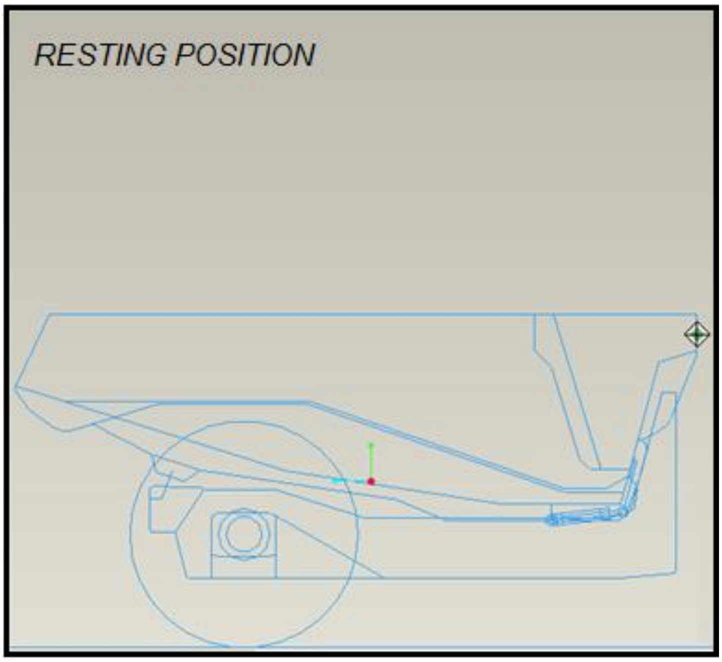


Figure 40: Two dimensional illustration of the Folding Box Concept 1 featuring a cylinder assembly in its lower front section. The box here is at its resting position and the cylinder is fully retracted.

Next, in order to find the stroke required in order to fold the frontal section of the box, the right constraints were added to the assembly. Figure 41 below, illustrates the box being lifted in a small angle while the frontal section folds towards the rear.

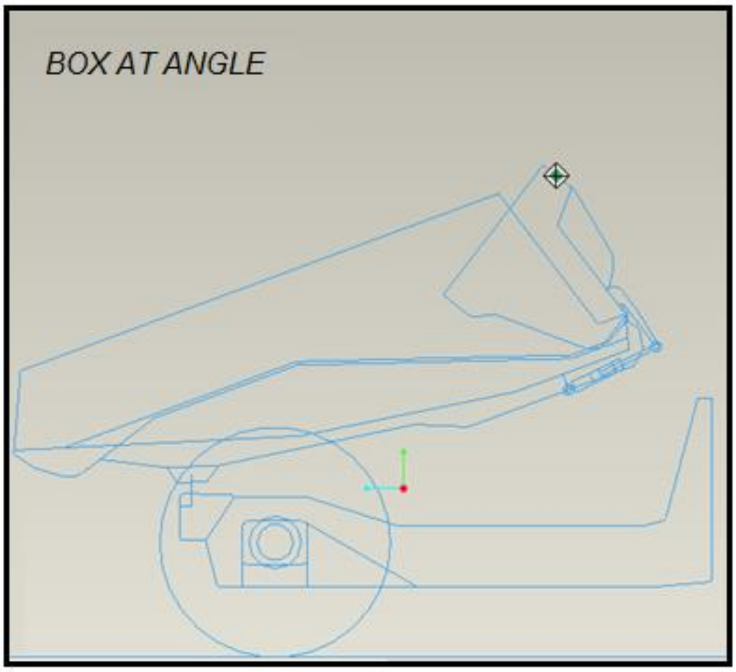


Figure 41: In this figure, the front section is being folded and the cylinder starts expanding.

Finally by reaching the maximum folding position, see Figure 42 below, the cylinder was fully expanded and the stroke distance was measured.

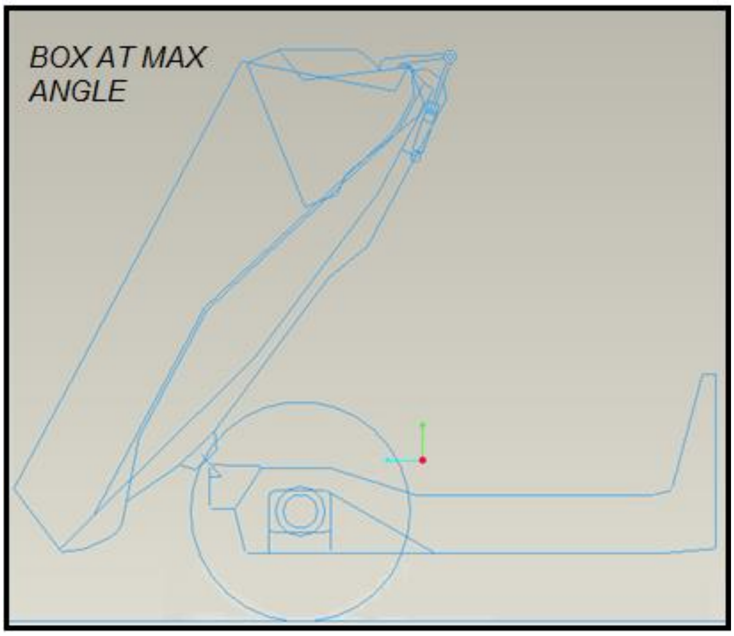


Figure 42: The maximum folding position, as illustrated in this figure, forces the cylinder to reach its fully expanded position.

With the help of the two dimensional working prototype, the stroke distance was measured to be: 259.49 millimeters ~ 260 mm of displacement.

Step 2:

The next stage, according to the plan, was to work out the sequence based on which the frontal section to be folded. As previously explained, in order for the folding box to be operated correctly, the front section had to be folded prior to the box reaching its upright position of 62º degrees.

However, the information received from a number of videos and pictures of the Standard Box configuration, suggested that up to large dumping angles, a large portion of the ore was still present in the box. This fact raised the question of how does the ore behave in a range of angles. In order to receive the needed information on ore flow, a simple observation test was conducted.

After looking through several options, a video of a previously used experiment was found. This video was made to compare various factors between the Standard Box and older box configurations. The experiment was conducted in a controlled environment and with two ore types, dry and wet ore. Although the actual purpose of this old experiment was not to document the behavior of the material in a range of angles, its data was found very useful and therefore it was used for the completion of this study.

Tables 4 & 5 below include all the important information documented by observing the small scale experiments. The angles documented throughout the two tests are accurate as they were measured with the aid of proper tools throughout the experiment however the mass value shown was estimated throughout the observation of the experiment for the purpose of this study.

Dry Ore Experimental Conditions:

Table 4: Dry ore behavior on a Standard Box configuration

Angle of the Box [in degrees]	Percentage of ore exiting the Box (%)	Mass of ore present in the Box [in kg]
0	0	42000
10	0	42000
15	0	42000
20	0	42000
25	0	42000
30	2	41160
35	30	29400
40	35	27300
45	45	2300
50	85	6300
55	95	2100
60	100	0

Wet Ore Experimental Conditions:

Table 5: Wet ore behavior on a Standard Box configuration

Angle of the Box [in degrees]	Percentage of ore exiting the Box (%)	Mass of ore present in the Box [in kg]
0	0	42000
10	0	42000
15	0	42000
20	2	41160
25	5	39900
30	15	35700
35	40	25200
40	40	25200
45	70	12600
50	85	6300
55	85	6300
60	100	0

As seen from the documented experimentation results above, the flow behavior between the two conditions varied. This difference was due to the level of humidity in the specimens of test one and test two. The main difference was observed in the mid-range of angles (30º - 45º). A general observation made by watching the video footage back to back was that wet ore seemed to stick together and flow more linearly through the box area whereas in dry conditions, a large portion of the was almost like trapped at the deep front section of the box, right at the start of the wheel arch section, up to the angle of 45º. Based on this information, the case of Dry ore was considered to be the worst case scenario for this study. According to the information gathered, the best moment to initiate the folding action was the highest angle possible where less ore was present in the box. The idea behind this was that the less material present in the box, the easiest would be to push the ore out of it and reduce the box's size. In theory, the maximum height on which the box could start folding was the one matching its maximum dumping position with a retracted front section. Keeping in mind the geometry and dump height values of both Concept 1 and 2, the moment of folding was recorded to be the angle of 32º. In this angle, the height of both boxes was around 4.5 meters and the estimated ore present in the box was around 29.400kg (dry ore conditions).

Step 3:

The next stage of the project was to estimate the force required in order to fold the box. As already known, the geometry of the rear box section in both Concept 1 and Concept 2 is very complex and it is made out multiple steel plates and surfaces that are forming the wheel arches, side walls and bottom section of the box. During the observation of the ore flow, it became clear that the box area affecting the ore flow was the deeper box section formed by the lower part of the wheel arches. Due to its shape, the frontal box section tends to trap a large amount of ore and the only way to get round the problem is to tilt the box up to a large angle. Figure 43 below, illustrates the position of the box when the folding action begins. The two reference angles illustrated are, angle α = 32º which represents the angle of the box cross section to the ground and angle β = 16.5 which represents the angle of the front wheel arch section to the ground.

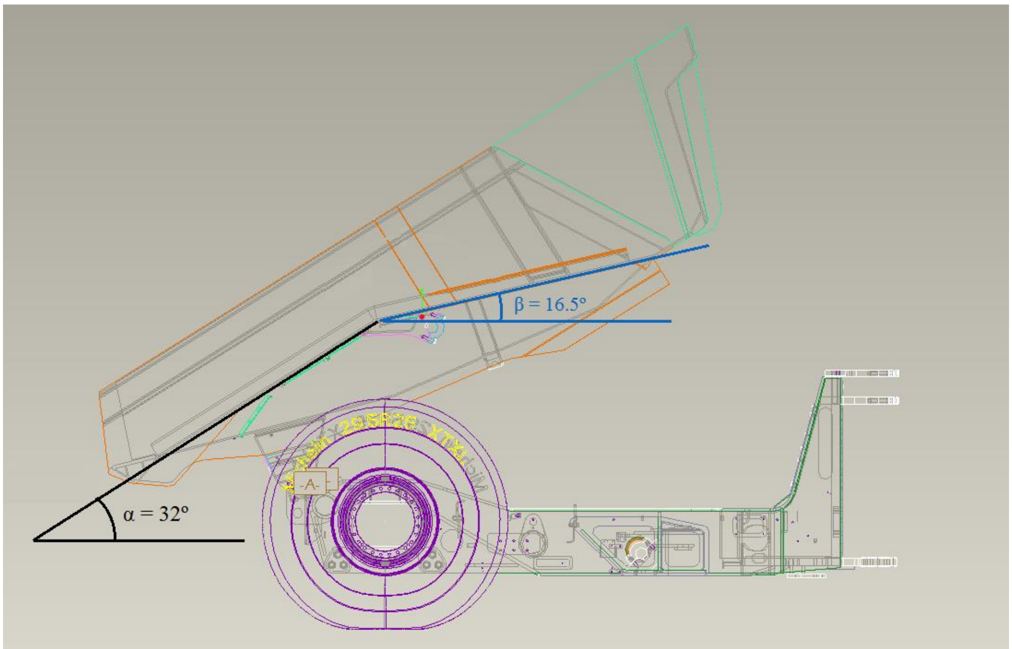


Figure 43: Example of Concept 2 layout and the important angles recorded. This position represents the height on which the box can start folding.

As seen from the figure above, angle β is the most critical angle and based on the experiment data, the section of the box where the majority of the ore is located in the worst case scenario of a dry ore condition. In order to estimate the force required for the cylinder assembly to operate, the following, simplified free body diagram illustrated in Figure 44 below was developed.

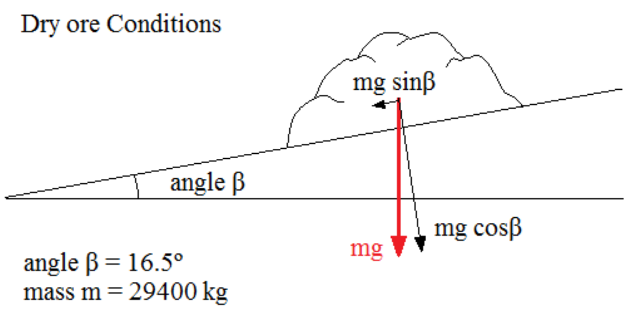


Figure 44: Free body diagram illustrating the case examined

As seen from the diagram above, there is no specific information on the friction value between the ore body and the box's surface. During the development of an actual product, a number of simulations and calculations are being performed by Atlas Copco Rock Drills to determine friction. However, in this case there was no information that could be used as a reference and therefore friction was neglected.

Due to this issue, the number used as the required force to push ore out of the 16.5º incline box section was an equal the (mgcosβ) force shown in the diagram.

Step 4:

At this stage, all unknown factors about the ore flow, box position and required force to operate the folding action were gathered. It is important to mention that since this was just a conceptual design, no design factors were taken under consideration. All the factors taken under consideration for the dimensioning phase of the cylinders are documented below:

- Number of cylinders: 2
- Application: Push
- Hydraulic Pressure: 196 bar / 19.6 MPa
- Piston Stroke: 260 mm
- Ore Mass: (29400 kg / 2) = 14700 kg per cylinder
- Gravitational Force g = 9.81 m/s^2
- Force Required: mg cos (16.5º)

$$\text{Formula used: Force} = \text{Pressure x Area} \quad (1)$$

$$\text{Area} = \frac{\text{Force}}{\text{Pressure}} = \frac{14700 \text{ x } 9.81 \text{ x } \cos 16.5}{19.6} = -5167.9 \text{ mm}^2$$

$$\sqrt{(\text{Area} / \pi)} = 40.5\text{mm in radius} \quad (2)$$

Therefore, according to the calculations above, the radius of the required cylinders to fold the front section of the box was found to be 40.5mm. This meant that the cylinders modeled for the completion of the conceptual design would have a bore diameter of 81mm. Using the stroke and bore values found a set of three dimensional CAD cylinders were modeled. Figure 45 below, illustrates an assembled cylinder unit.

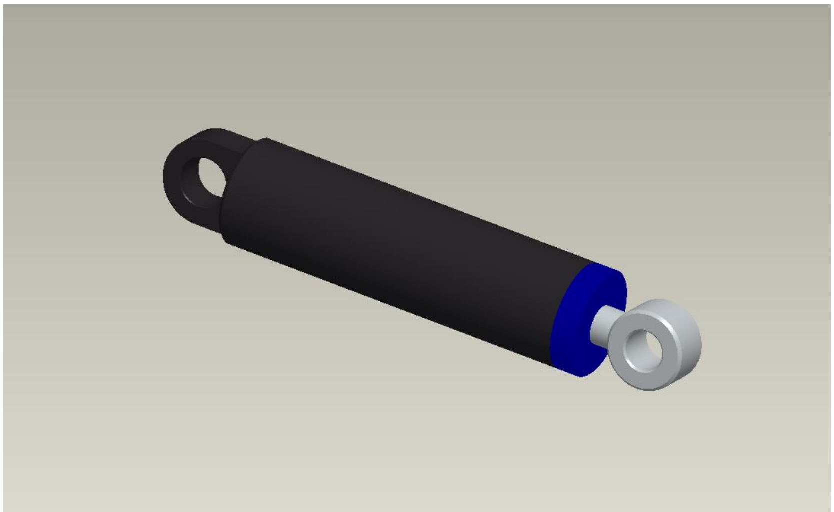


Figure 15: Simple three dimensional model of the hydraulic cylinder unit designed.

3.2.6 Folding Box – Finite Element Analysis

An important parameter for the comparison between Folding Box Concept 1 and Folding Box Concept 2, was their assessment in a Finite Element environment. With the conceptual design and box reinforcement phases complete a structural assessment of the two box concepts begun. The assessment was divided into two separate parts, the ‘Normal operation loading case’ and the ‘Side collision loading case’. These two cases are often used for the development various box layouts and their purpose it to assess the durability and structural integrity of a structure under common working conditions. The following paragraphs, give an insight of the conditions and constraints used in the two loading cases used for the comparison assessment of the two Folding Concepts.

A. Normal Operation Loading Case

The first of the two conditions that was applied in both concepts was the Normal operation loading case. The purpose of this loading case was to replicate the condition where a box is fully loaded with ore while driving down a mine tunnel in speed. A common fact about mine tunnels is that their path can be rough, causing the material in the box of a Minetruck to violently shift while driving through. Due to the rough road terrain, the load being carried at the rear end of a Minetruck multiplies, increasing the risk of a structural failure. The aim of this assessment was to replicate this case for the three dimensional models of Concept 1 and Concept 2. The ‘Normal operation loading case’, was just focused on the rear box section and no more components were added to the FEM assessment in order to keep everything to a simple and conceptual level. The loading conditions applied were in two general directions, vertical load and side load. The following figures, Figure 46, show how forces were applied in both Concept 1 and Concept 2.

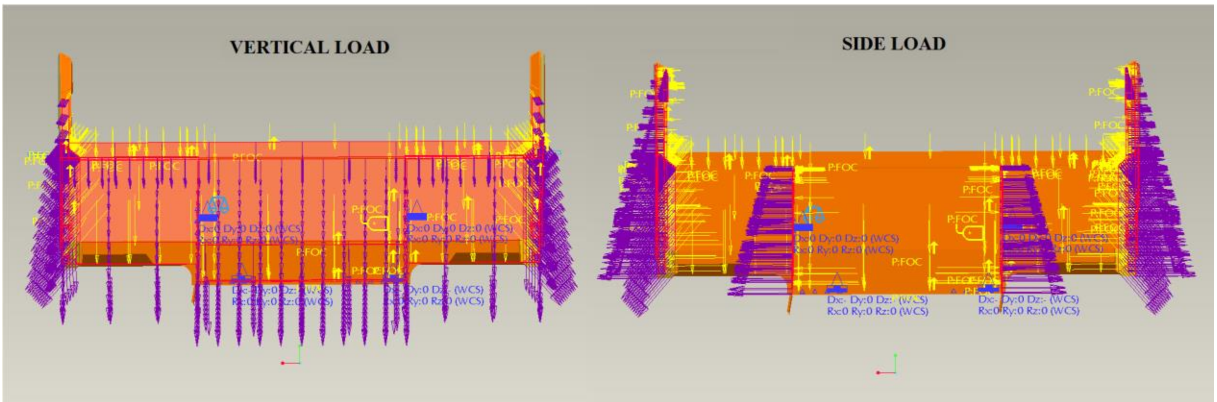


Figure 46: Front view of the vertical and side loads as applied on the Rear box sections of Concept 1 and 2.

An important observation that can be made by looking at the load vectors is the fact that the Vertical load case is linear all across the box. In a real case scenario, due to the way ore or other dense material stacks up, the vectors would be larger on the center of the box and smaller on the side. Therefore, this example does not represent a real case scenario with a heaped load but a more simplistic loading calculation approach. In the case of the side load, a more accurate approach was selected with the vectors being larger at the bottom side section.

Once the loads were applied in both box models, it was time to sort out the required constraints for the completion of the FEM assessment. The first of the constraints added was the selection of the resting points in both Concept 1 and Concept 2. Due to the geometry and layout similarities, the rear resting point looked exactly the same. Figure 47 below, illustrates the surfaces and conditions added to the rear end of both rear box sections.

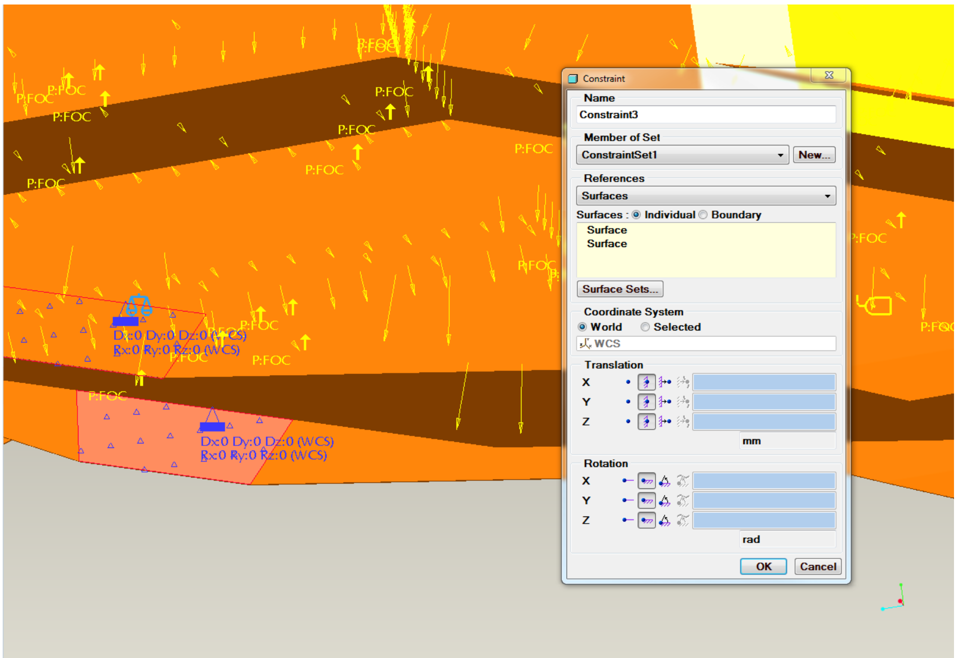


Figure 47: Selection of the correct conditions on the rear end of a box section.

The next set of constraints was added at the lower part of the rear box sections in the form of general resting points onto the chassis. Since the Normal Operation Loading Case replicates the conditions of a box while a Minetruck is being driven, the box was assumed to be in its normal resting position. Although Concept 1 and Concept 2 have a very similar geometry, the resting point at the front part of the rear section was slightly altered by few millimeters due to minor geometry alternation. Figure 48 below, illustrates an example of the constraints as used in Concept 1 – Hinge location high box layout.

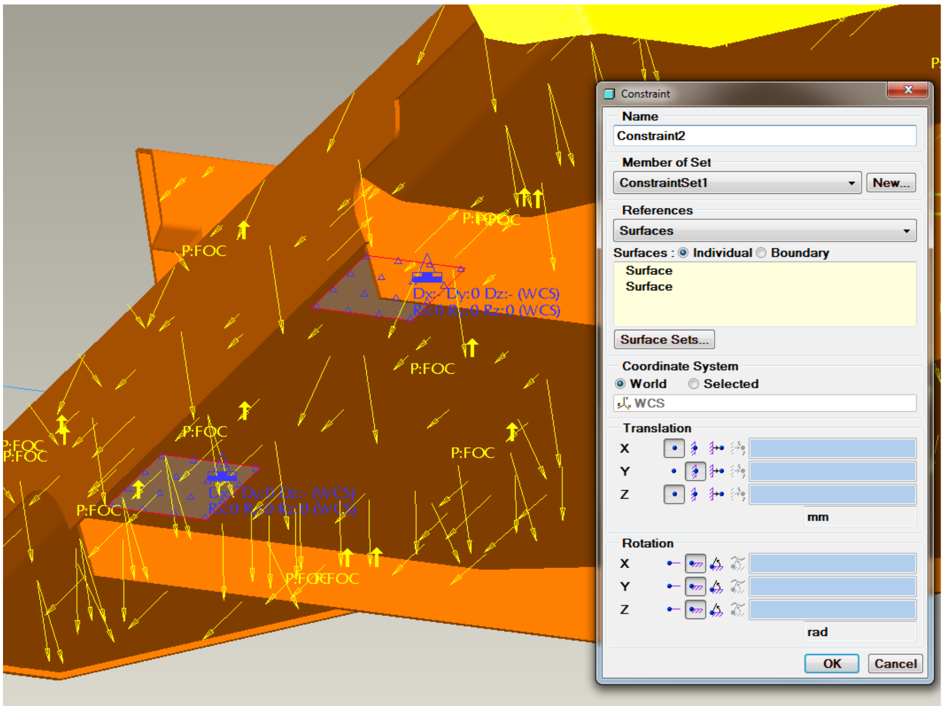


Figure 48: Illustration of the constraints used at the front part of the rear box section.

A. Side Collision Loading Case

The second of the two loading cases examined was another common operational condition. The thinking behind Side Collision is that while in the material handling process, a Minetruck often interacts with large loaders that drop substantial quantities of ore from the Minetruck's side into the box. In many cases recorded, loaders such as the Atlas Copco Scooptram have had a collision with the Minetruck box while in the process of loading. In a common box configuration where all box sides are connected, collisions such as the one described have not been a big issue. However, in the case of the Folding Box Concept 1 and Concept 2, where the boxes are built out of two separate sections, a side collision could have a direct effect on the structure shape. The concern is that a small, side deformation on one of the box sections could potentially alter the clearance between them. In order to examine the worst case scenario of a side collision, an FEM assessment replicating the result of a collision with the largest Atlas Copco loader configuration was assessed.

The constrains considered for the completion of the Side Collision case were kept the same with the ones used in the Normal Operation Loading Case explained earlier. The reason for this is that the box would be kept in the same exact resting position in both loading cases.
The side collision was replicated with the placement of a side load in a confined space directly at the side of the box. The same condition was applied in both Concept 1 and Concept 2 and the results were recorded. Figure 49, illustrates the side collision load being applied on the upper side wall of Concept 1.

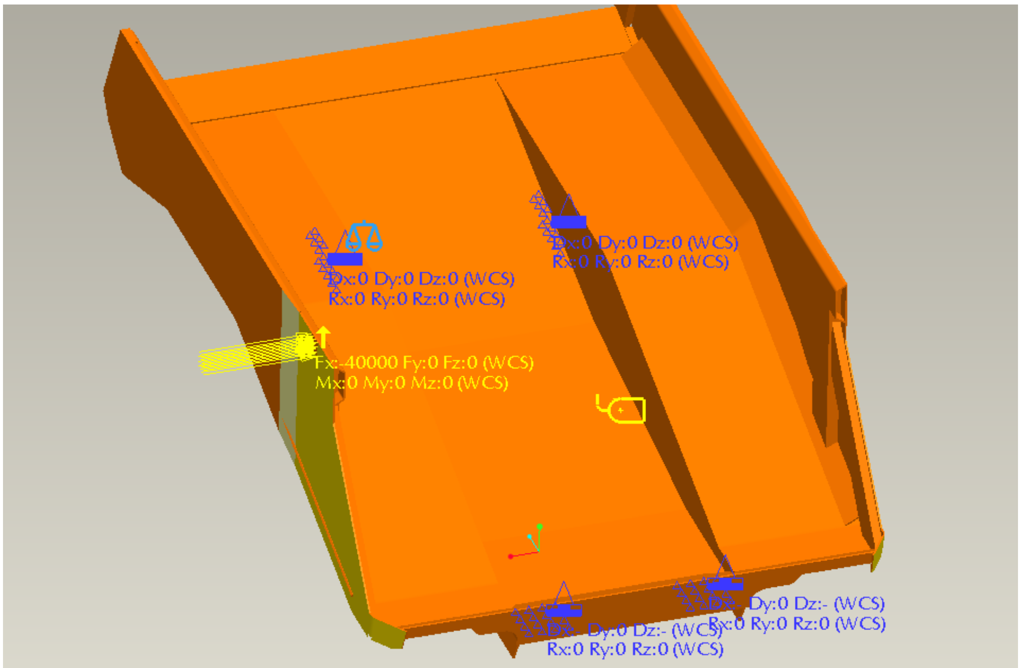


Figure 49: Side load (marked in yellow) applied in the rear box section of Concept 1

The end results observed during this Master Thesis feasibility study are presented and analyzed in this part of the report.

4.1 Finite Element Analysis Results

In this paragraph, the results and observations made for each one of the FEA loading cases applied in the prototype concept boxes will be presented. The first of the two loading cases to be applied was the Normal Operation loading case.

A. Normal Operation Loading Case - Results

As already explained this loading case was selected to represent the effect that driving in a rough mine tunnel terrain can have on the structure. Once all conditions were set, a Stress Von Mises representation was plotted for both Concept 1 and Concept 2. According to the data recorded the load on the boxes once the assessment begun was 30.000 kg (30 tons). Figures 50 and 51 illustrate the Von Mises Stress in Concept 1 and Concept 2 respectively.

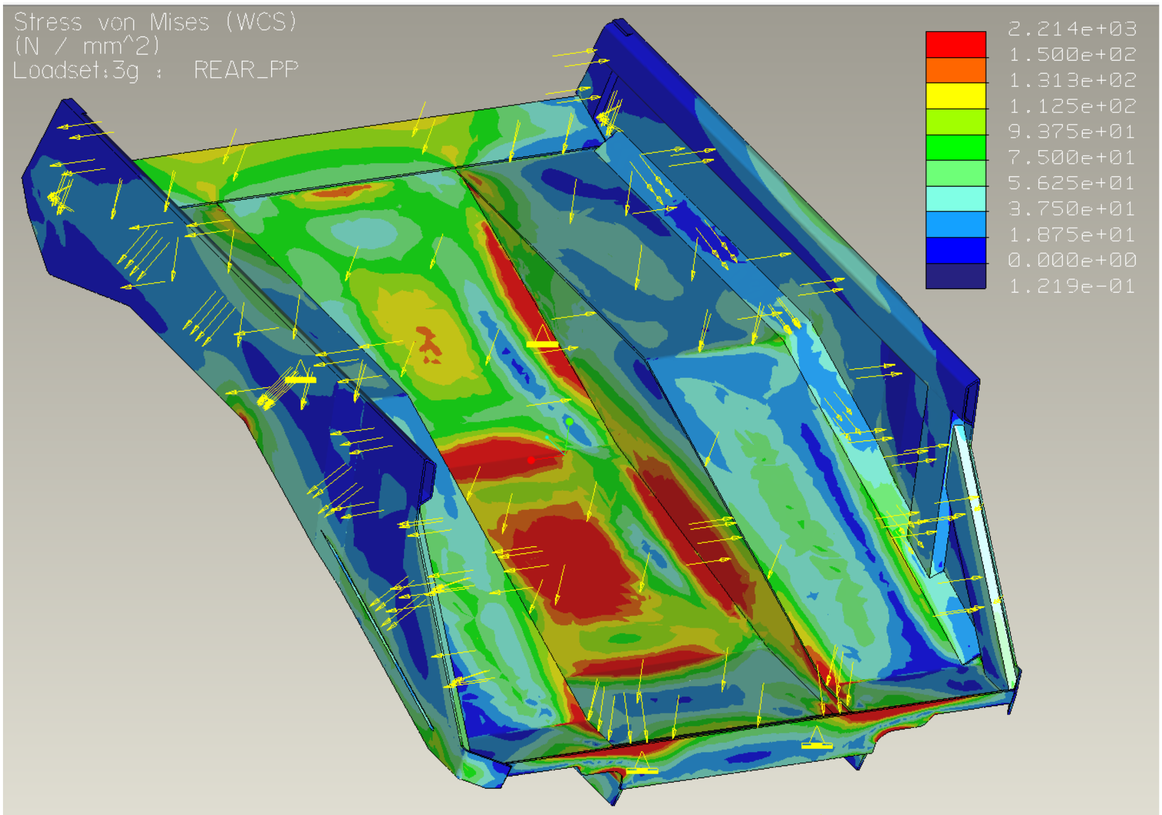


Figure 50: Stress Von Mises recorded for Concept 1. Ore load on the box structure = 30 tons

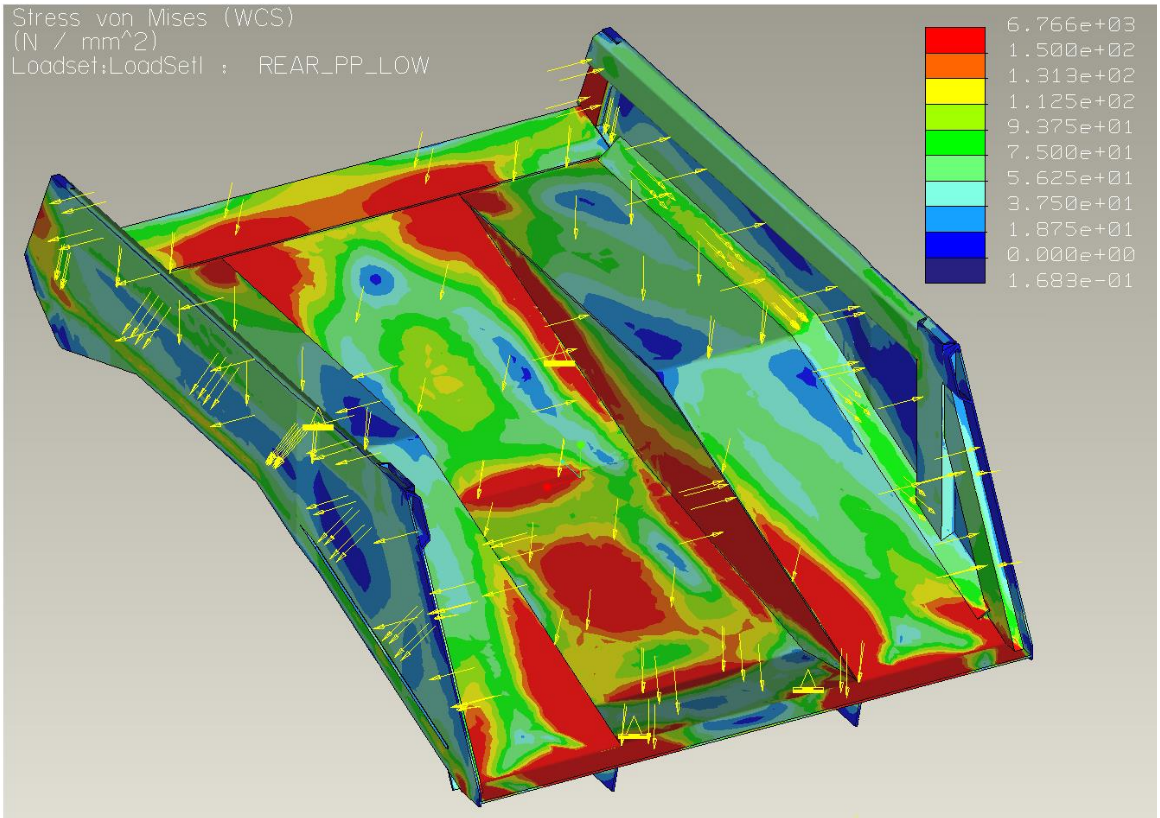


Figure 51: The Stress Von Mises recorded for Concept 2. Ore load on the box structure = 30 tons

The Stress Von Misses plots of the two rear box sections revealed a number of useful information:

First of all, the most obvious difference among the two plots is the spreading of color all across the box. The fact that the Box structure in Concept 1 has been divided in the lower section of the front wall appears to have a very positive effect in the way stress spreads. The front section of Concept 1 works as a strengthening component between the sides and the floor of the box holding the structure together. The maximum stress reached once Concept 1 box is being exposed to the conditions of the Normal Operation loading case assessment appears to be 2214 MPa. Looking at the Von Mises Stress plot of Concept 2, we can immediately see the effect that the lack of a front floor section can have in a box structure. The fact that there is no floor section acting as the strengthening component between the floor and sides allows the stress to be spread all over the structure. The box's side panels seem to be also affected by the lack of a frontal strengthening element and therefore the whole structure appears to be more vulnerable to high stresses. It is important to mention that the highest value of stress recorded by the FEA software in the case of Concept 2 was 6766 MPa almost three times the value recorded in Concept 1.

B. Side Collision Loading Case - Results

Another critical comparison during the Finite Element study of the two Folding Box Concepts was their performance under a side collision scenario. Figures 52 and 53, illustrate the results recorded for the worst possible case of collision between a loader and a rear box section.

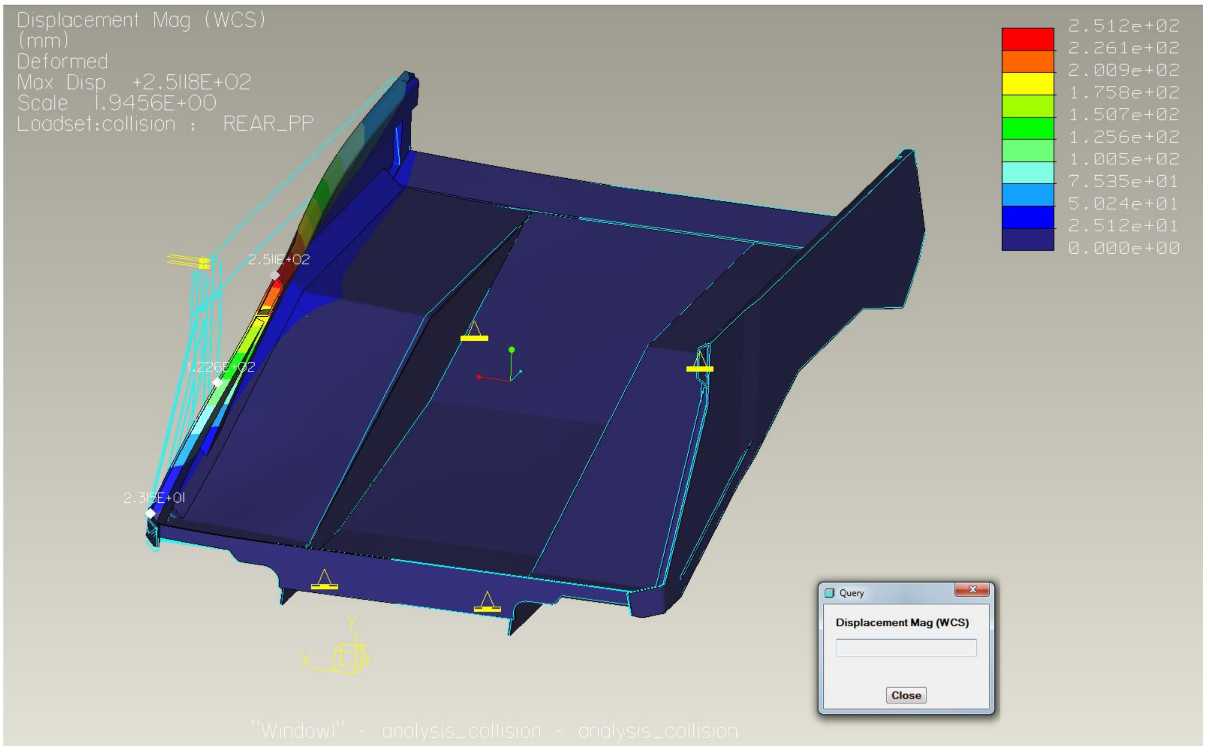


Figure 52: Plot of the displacement after a side collision with a large loader – Concept 1. The effect of the graph on the scale has been visually increased due to the default software setting. The actual value of Maximum displacement recorded for this case is 251.2 millimeters.

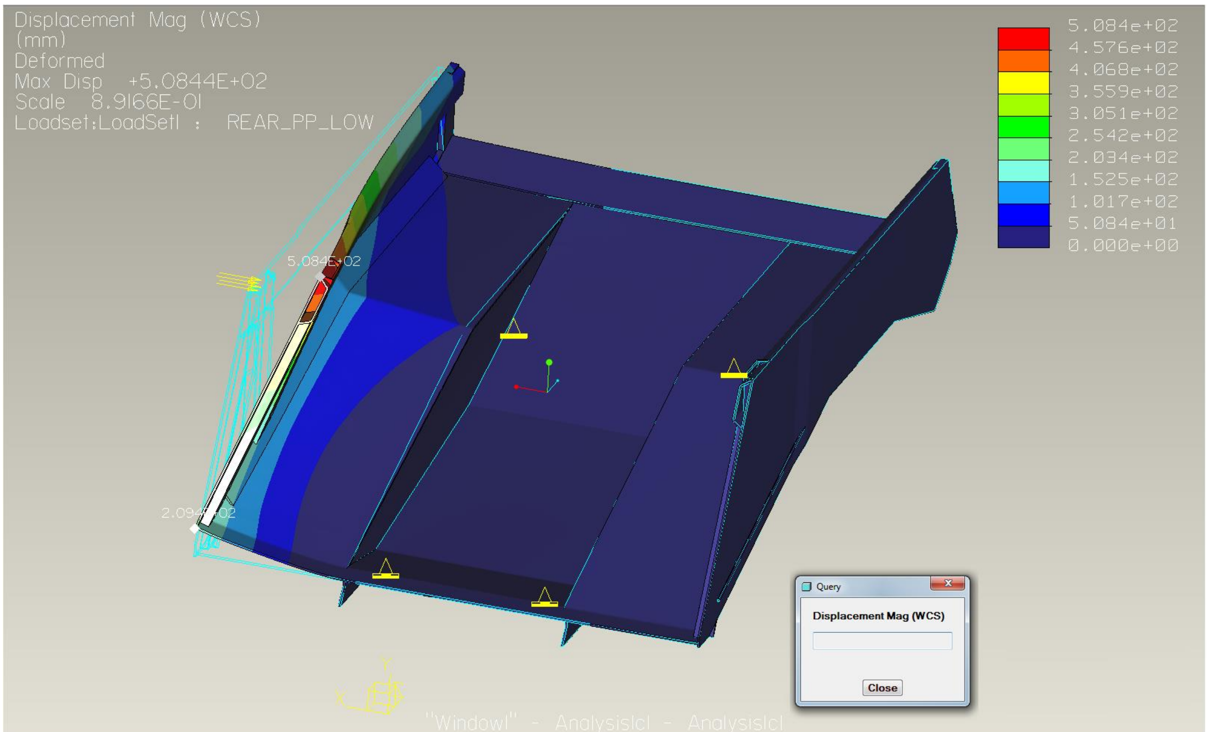


Figure 53: Plot of the displacement after a side collision with a large loader – Concept 2. The effect of the graph on the scale has been visually increased due to the default software setting. The actual value of Maximum displacement recorded for this case is 508.4 millimeters.

Before further analyzing the results recorded in the Side Collision loading case above, it is important to note that although a common issue in a mining environment, a real life side collision case would probably have a smaller effect on the structure. A very critical factor that has not been taken into account on this representation is the Minetruck's tire deflection which acts as an absorber in such conditions allowing the whole chassis and box structure to swing by few millimeters. Furthermore, in order to replicate the worst case scenario, the option of the largest possible loader was selected. Therefore in a real life example, the deformation values recorded would be less severe.

By looking at the deformation plot of both Concept 1 and Concept 2, it is evident that a potential side collision on a rear box section of this layout has a severe deformation effect in its structure. When comparing the two deformations visually, it is clear that Concept 2 is more vulnerable to a deformation again due to the lack of a front floor section holding the frontal part of the box structure together. An interesting fact is that in Concept 2, the side collision seems to have an effect not only on the side wall but also at the lower front section of the large wheel arch, forcing it to bend. By comparing the deformation number as recorded with the aid of the Finite Element software used, the fact that Concept 1 was subjected into less damage is also confirmed. The maximum recorded deformation in Concept 1 was 251.2 millimeters as opposed to 508.4 millimeters in Concept 2. Therefore, it can be said that the deformation in Concept 2 is twice as much as the deformation shown in the case of Concept 1.

When considering the results recorded for each of the two FEA assessment cases, it can be said that both pose a number of disadvantages. To begin with, for the Normal Operation load case, the weight added to the boxes was up to 30.000 kg. The reason for this was that in their conceptual design state both Concept 1 and 2 were not able to hold a larger amount of ore. By experimenting with the Stress Von Misses and the General Fatigue value of welding, it was clear that in order for a larger portion of ore to be added at a divided box section, a whole redesign of the layout would have to be attempted. However, it is safe to say that when comparing the two concepts under the first loading case, we immediately saw the advantage of having a hinge location higher in the box. The addition of a floor at the frontal part of the rear box section was proven to be an interesting concept as it had a very positive effect on the way the structure behaved. During the second loading case assessment, both Folding Box prototypes went through the worst case scenario of a side collision, with a large loader vehicle. The most interesting observation was the large displacement caused during the collision on the side of the box. In both models recorded the displacement and stress values measured were high. However, by more comparing the two concepts, Concept 1 had the best results recorded by far. Taking all the information collected under consideration, the most feasible out of the two concepts was Concept 1 with the hinge location high.

4.2 Folding Box Concept – Design and Specifications

Considering the structural advantages of Concept 1 over the ones observed for Concept 2, it was clear that Concept 1 was an all-round better layout for fulfilling the purpose of a folding box. Throughout the FEA assessment, it became clear that Concept 1 needed further reinforcement to be able and withstand a larger load. However due to the lack of time and since the idea of a folding box was still a concept; no further work was done to improve its capacity and structural behavior. Instead, it was decided that in order to get a better view of how the completed concept would look like and to document all important specification values, the creation of a more complete prototype begun.

Based on the initial Concept 1 folding design, the new model would feature a number of extra features. First, a pair of cylinder mounts was added at the bottom part of its rear box structure to allow for the installation of a hydraulic cylinder pair. Second, the front box section was also slightly modified to allow for the box to reach an even larger angle before folding it. This was achieved by reducing the upper hatch dimensions. By doing so, the vital articulation components located between the two chassis would be protected by the addition of a different solution that already exists as an option in the current product range of Atlas Copco. Furthermore, a set of swing arms were placed on the front box section to allow for the cylinders modeled to perform the folding function.

The complete assembly of the final concept and its design characteristics are illustrated in the following in Figures 54, 55 & 56 below:

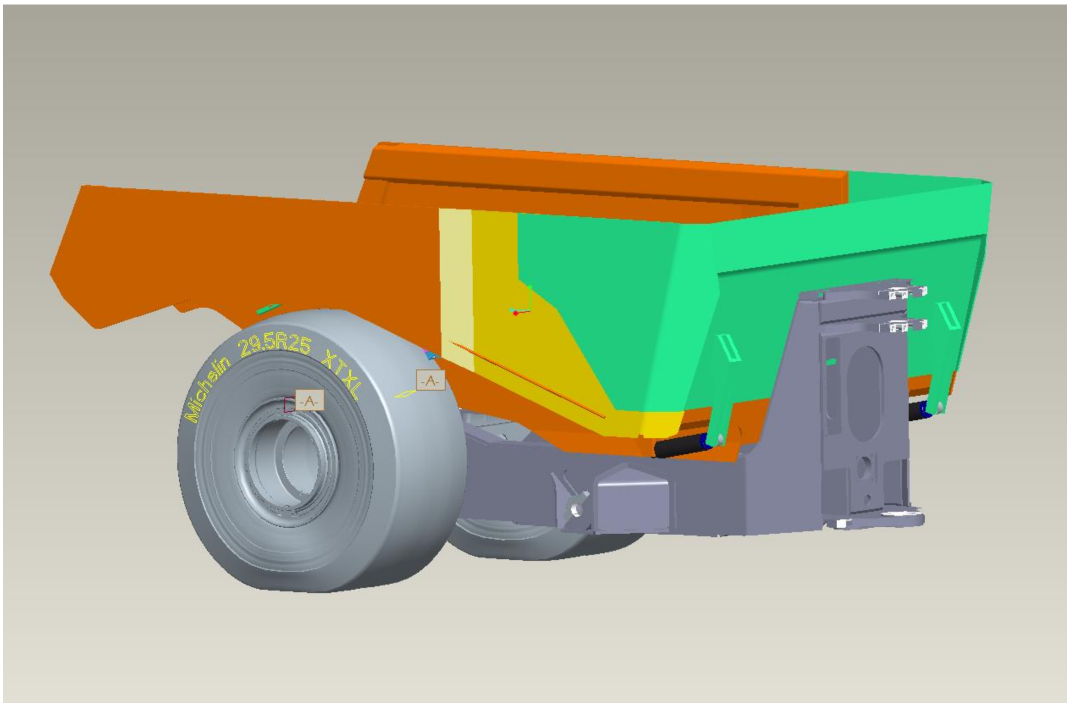


Figure 54: The complete assembly of the final Folding Box proposal. It is important to mention that a hinge system and the main two hydraulic cylinders for raising the box were not included in the final assembly.

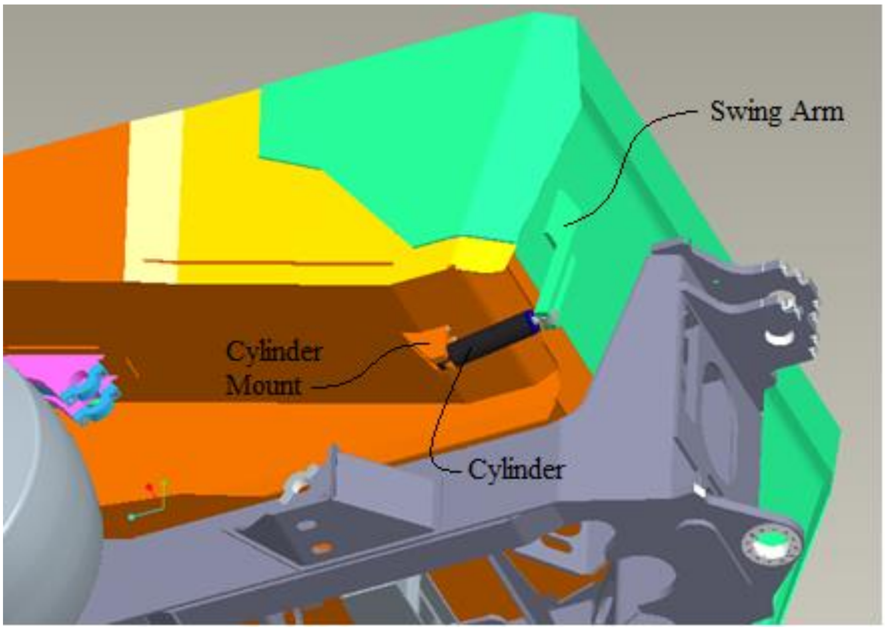


Figure 55: The cylinder installation setup designed for the final Folding Box proposal.

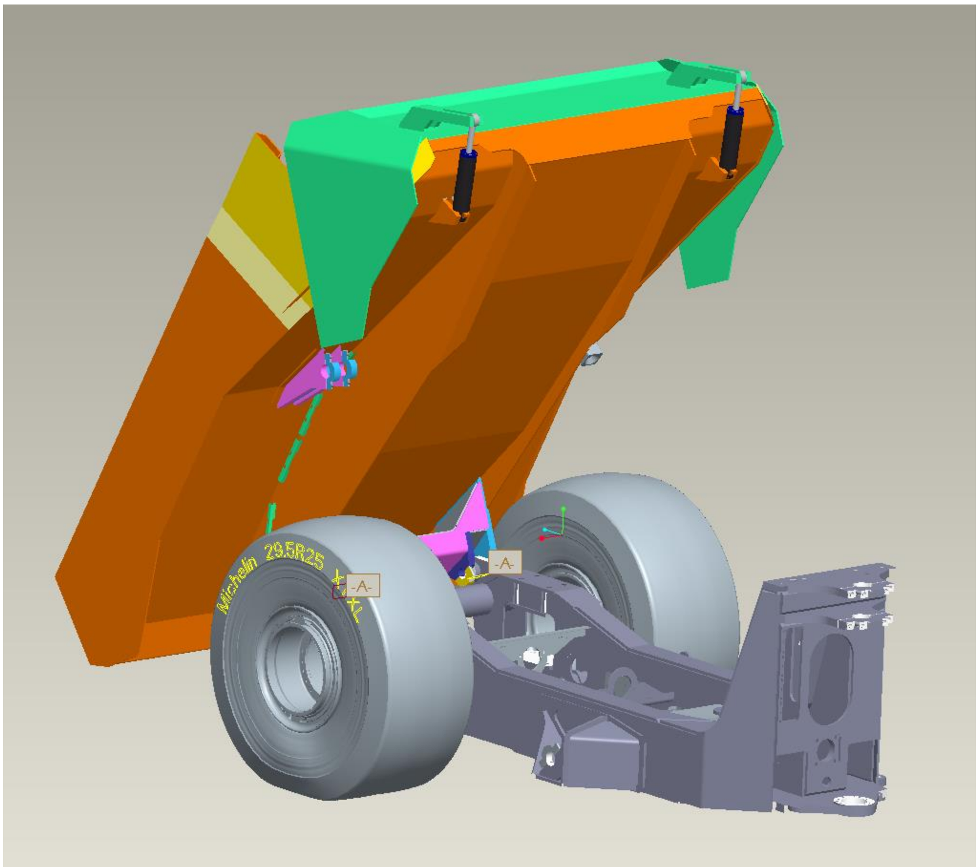


Figure 56: A view of the final Folding Box proposal in its upped dumping position.

With the completed model of the Concept in three dimensions, it was time to recap and gather all information gained on a specification table like the ones made for the current product range configurations. Table 6 below, includes all the important specification values related to the final proposal of the Folding Box configuration. It is important to note that these numbers reflect the specifications of the simplified CAD prototype built and do not represent a real life production ready model. Therefore values such as the structure weight and the dumping cycle time are not very accurate.

Table 6: The most important performance specifications documented for the new Folding Box configuration concept

Parameter	Units	Value
Ore Density	[1000Kg/m^3]	2.2
Volume of Ore Transported	m^3	15.3
Payload	Tons (t)	30.0
Structure Width	mm	3050
Dump Height	mm	4600
Structure Weight*	kg	5000
Dump Cycle Time (est.)	sec	30
Payload / Structure Weight	Ratio	6.0

*Note: *The value of structure weight includes both Box sections, pivots, and Hydraulic cylinders as modeled for the completion of the simplified conceptual design. The Standard Chassis frame, rear Wheels and axle were not considered.*

4.3 Current Box Range vs Folding Box Concept

Having gathered all the useful specification parameters from the Current box range and the new Folding box proposal, it was time to conduct a simple comparison assessment between them. The purpose of this assessment was to get a side by side comparison of the most important parameters that would eventually determine if there is a value in the continuation of the Folding Box project. Table 7 below, includes all important information considered.

Table7: Comparison table of all specification data collected for current range products and the new folding box concept proposal.

	Ore density ρ	Volume of the Ore Transported	Payload	Dump Height	Dump Cycle Time	Structure Weight	Payload / Structure Weight
	[1000kg/ m^3]	[m^3]	[Tons]	[mm]	[sec]	[kg]	[Ratio]
Standard Box	2.2	19	41.8	5640	16	5350	7.8
Ejector Box	2.2	17	37.4	2815	30	9350	4.0
Teledump Box	2.2	14.5	35.5	3895	35	8200	4.3
Folding Box	2.2	13.6	30.0	4600	20	5000	6.0

As seen from the data table information, the comparison was conducted considering the same ore volume in every single one of the configurations examined. Right from the start, the ore volume and box capacity advantage of the Standard box configuration can be seen. Due to its simplistic and lightweight construction the Standard box, can transport a larger portion of ore within a mine. This can also be seen by the Payload / Structure weight ratio that is significantly higher to when compared to the rest of the examples documented. This proves that as a design, the Standard box is a very efficient and good solution. However due to its increased dumping height, this configuration cannot be used in a backfill mining application. The Ejector box in its current state seems to be the second best option in terms of ore volume and capacity specifications. However, its biggest advantage can be clearly seen when considering dumping height. The dumping height value of an Ejector box configuration was measured to be just 2815 millimeter, a difference of 1080 millimeters to the next best low dumping height solution of a Teledump box. Looking at the specifications of the Teledump, it is evident that size wise is smaller than the Standard and the Ejector box products. The Volume and payload values were significantly less and this was due to the fact that it was designed back in the day as a solution for a shorter Minetruck chassis. However, the important fact is that with its integration to the current chassis in production, the dumping height of a Teledump configuration was still below the 4 meter goal that was requested from the marketing department and the various Atlas Copco clients. This means that while operating in an underground mine, this Teledump configuration would be able to complete a Backfilling cycle in a low height ceiling environment. Moving on, to the latest concept, the Folding Box, we can immediately see that it has the smallest capacity compared to the other box configurations, although its geometry is based on the Standard box design. The reason for this limitation was not the dimensions of the box but the fact that its structure while subjected to the Normal Operation load case could not cope with a higher cargo load than 30 tons. Therefore, at its current conceptual state the Folding box remains the one with the least payload and cannot compete with the 40 ton cargo Minetrucks. Another important factor that can be observed for the case of the folding box is its low value of structure weight. Although this can be claimed to be a large advantage over the rest of the configurations tested, it is important to consider that being a concept, a number of shortcuts were taken during its design phase. The Folding Box unit was based on the Standard Box and its main Structure, i.e. box sections, box mounts to the chassis, lifting cylinders, etc., were more or less same. According to some assumptions made by the design team in Atlas Copco Örebro, a more production ready version of the Folding Box would probably weigh closer to 6000 kg rather than 5000 kg and still be able to handle a load closer to the 30 tons margin. However, perhaps the biggest disadvantage performance wise that can be seen from the data collection table is the fact that the dumping height of the Folding Box concept was 600 millimeters more than the aimed 4 meter goal aimed during the project. When compared to the Teledump, the dumping height difference is 705 millimeters and when compared to the latest addition of dumping systems, the Ejector Box, the difference is 1785 millimeters. In other words, while comparing the specification values gathered throughout the feasibility study, it was clear that the Folding Box concept was outperformed by the current range solutions. In order to get a more graphical description of this comparison, the chart illustrated in Figure 56 below was created.

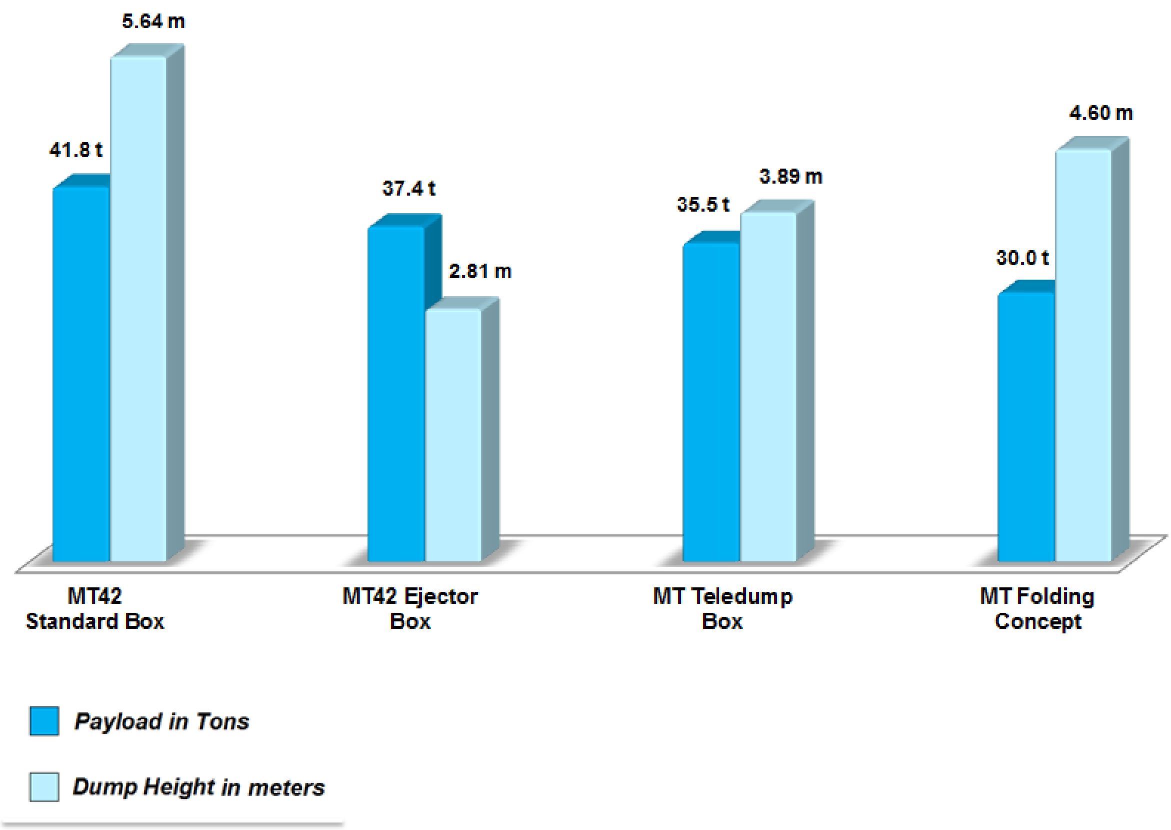


Figure 56: Graphical representation of the Payload and Dump Height for each of the configurations examined.

As seen from the graphical representation above, the two configurations with the most potential in terms of a box that can cope with the 4 meter dump target are the Ejector and the Teledump Boxes. These two boxes are already tested solutions and despite their heavy box structure, they can still carry significantly more cargo than the proposed Folding Box Concept, due to their solid box geometry.

5 DISCUSSION AND CONCLUSIONS

A discussion of the results and the conclusions that the authors have drawn during the Master of Science thesis are presented in this chapter. The conclusions are based from the analysis with the intention to answer the formulation of questions that is presented in Chapter 1.

5.1 Discussion

The actual purpose of this Master Thesis was to initiate a feasibility study based on a patented idea of a Folding Box that was triggered from the needs of the current underground mining market. As already explained in this report, a low ceiling dump vehicle is an important addition to the machinery used in various underground mines all over the world. The reason is the fact that it can result to a large economy in mines due to its size reduction capabilities that require less work being done while developing underground mines. Furthermore, a low dump height vehicle can be used for backfilling applications using rock waste in narrow tunnels. The idea of being able to empty material in a more confined space has been around for the past years and Atlas Copco has been working on a number of low ceiling dump solutions, two of which were presented in this Master Thesis report. The study begun by the collection of all vital design and performance information found in documents, drawings and through three dimensional models of the current range vehicles. The plan was to use this information in the later stages of the report and develop some kind of a performance comparison assessment between the current range products and the new concept. The design of the concepts presented in this report was based on information received from the official patent paper as well as the given customer demands. During this project two different folding box configurations were designed and assessed. It is important to note that the simplified design approach to this project was suggested due to the limited time. The completion of a detailed box design up to the company's standards is a very rigorous process that engages a large team of engineering experts and cannot be undertaken in the short period of a typical thesis study. As explained throughout the report, the same conceptual approach was followed while working on the FEA analysis of the two Folding concepts designed. The FEA assessment presented on this report was completed with the aid of 'ProEngineer Mechanica' software and only for two basic load cases. This assessment however, helped in the identification of the advantages and disadvantages that each of the two Folding Box concepts presented had. Unfortunately, again due to the limited project time frame, further improvements on the box geometry after the Finite Element assessment were not attempted.

However, by following the above described methods, vital information that could not have been assumed without the initiation of this short feasibility study was revealed. First of all, the translation of the two dimensional sketches of the patent paper to fully working three dimensional CAD models, helped in the realization of the important components required in the development of such a design and the needed modifications that had to be done. Next, the use of a Finite Element Analysis approach for the comparison of the two different Folding Box concepts, revealed the importance of keeping the bottom section of a box intact and moving the hinge location to a vertical section of the box such as the front wall. Finally, the information gathering from the current range products such as the Standard, Ejector and Teledump boxes helped in the formation of a valid comparison assessment between the already developed and approved Minetruck options and the new Folding Box idea.

5.2 Conclusions

By following the above described methods, the final answer to the feasibility of the Folding concept was given. Dividing a box into two parts as in the method described in the folding box patent paper, appears to give a number of complications in the structure of the Minetruck box used as the study reference. The largest complication was found to be the load case of side collision during of which the divided box of the proposed folding configuration showed a large deformation. As explained earlier in the report deformations of the geometry between the two interacting box sections can potentially lead to an early failure of the folding function. These complications were confirmed by the Finite Element Analysis of the conceptual box designs. When comparing the current range options to the proposed Folding Box design, structural weight was taken under consideration. The idea was that the lighter the box would be, the more ore it would be able to carry throughout a single working cycle. However as observed from the results of the FEA, the Folding box concept was at its limit with a load of 30.000 kg, 12.000 kg less than the initial aim. Taking under consideration the structural issues faced in both load cases it was evident that in order to improve the current design, the addition material to the structure would be necessary. Furthermore, the geometry of the box and the importance of keeping its bottom section intact lead to a small height reduction, bringing the overall height of the Folding Box to 4600mm when folded. This is not necessarily a bad result, however, when comparing it to the two current low ceiling duping solutions that Atlas Copco has already developed and produced it is easy to see why the further development of the Folding Box idea would not be a recommended solution for Atlas Copco.

6 RECOMMENDATIONS AND FUTURE WORK

In this chapter, the general recommendations for the future of this project are being presented.

6.1 Recommendations

Although a very interesting alternative to the current range solutions, the Folding Box idea seemed to have a number of complications in the way it was applied in this project. By converting a Standard Box to a Folding Box structure, the main performance limitations were found to be in the shape of the actual box and not in the axle or Minetruck chassis design. The main issues found in it where involved around geometry limitations and structural integrity. The fact that some of the complications can be perhaps eliminated by further improving the Folding Box design is true. However due to the existing Atlas Copco low ceiling dump Minetruck solutions such as the Ejector and Teledump boxes that outperform the Folding Box in every aspect, further development and improvement of this solution would not be a reasonable investment. Therefore, the idea of a folding function for height reduction could perhaps be used in different machinery hardware or in different box geometry in the future.

6.2 Future Work

Taking under consideration the superiority of the Ejector box and the Teledump configuration, in terms of dump height, cargo weight and structural integrity, it would make sense for URE, Örebro to focus on their improvement for the near future. One of the possible improvements could be the integration of the whole Chassis, or a part of the Chassis in an Ejector Box configuration with the actual box structure. This would potentially decrease the overall weight of the box and allow for a larger payload, increasing the Payload / Structure weight ratio and therefore improving the efficiency of the Vehicle.

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APPENDIX: MASTER THESIS GANTT CHART