ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

MSc THESIS

Erinç ULUDAMAR

DEVELOPMENT OF A SPECIAL SIDELIFTER FOR TRANSFERRING CONTAINERS BETWEEN RAILROAD FREIGHT CARS AND TRAILERS

DEPARTMENT OF MECHANICAL ENGINEERING

ADANA, 2012

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES

DEVELOPMENT OF A SPECIAL SIDELIFTER FOR TRANSFERRING
CONTAINERS BETWEEN RAILROAD FREIGHT CARS AND TRAILERS

Erinç ULUDAMAR

MSc THESIS

DEPARTMENT OF MECHANICAL ENGINEERING

We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 09/01/2012

…………………..................... ……………………………… ……………………………………
Prof.Dr. Kadir AYDIN   Assoc.Prof.Dr.Hakan YAVUZAsst.Prof.Dr. Kerimcan ÇELEBİ
SUPERVISORMEMBERMEMBER

This MSc Thesis is written at the Department of Institute of Natural And Applied Sciences of Çukurova University.
Registration Number:

Prof. Dr.İlhami YEĞİNGİL
Director
Institute of Natural and Applied Sciences

ABSTRACT

MSc THESIS

DEVELOPMENT OF A SPECIAL SIDELIFTER FOR TRANSFERRING CONTAINERS BETWEEN RAILROAD FREIGHT CARS AND TRAILERS

Erinç ULUDAMAR

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF MECHANICAL ENGINEERING

In this study, a container loading and unloading mechanism which is assembled on a semi-trailer, is designed and manufactured. This design is supported with a mechanism which can be adjusted according to different dimensioned ISO standard containers. The main requirement of the above mentioned mechanism is the ability of loading and unloading of ISO containers up to 12,192 m long on every ground condition except at very soft and slope grounds. Design concepts created in this manner are firstly tested by the analysis softwares. The analysis results are then used in selecting the most successful design concept to be manufactured as a prototype for performance tests. The results of the performance tests are also presented.

Key Words: Container, Sidelifter, Logistic, Simulation, Finite Element Method

ÖZ

YÜKSEK LİSANS TEZİ

RÖMORK VE YÜK VAGONLARI ARASINDA KONTEYNER AKTARMAK İÇİN ÖZEL BİR SİDELİFTER GELİŞTİRİLMESİ

Erinç ULUDAMAR

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
MAKİNE MÜHENDİSLİĞİ ANABİLİM DALI

Bu çalışmada, römorkün üstüne yerleştirilmiş yeni bir konteyner yükleme ve indirme mekanizması tasarlanmış ve üretilmiştir. Bu tasarım, değişik boyutlarda ISO standartlarına göre üretilmiş konteyner boyutlarına uygun bir şekilde ayarlanabilen bir mekanizmayla desteklenmiştir. Bahsedilen mekanizmanın tasarımındaki ana kriter; 12,192 m uzunluğa kadar olan ISO konteynerini, çok eğimli ve yumuşak olan zeminler hariç, her türlü zeminde yükleme ve indirme yapabilmesidir. Bu doğrultuda yapılan tasarımlar ilk önce bilgisayar ortamında test edilmiştir. Bu analiz sonuçları, performans testleri için prototip olarak üretilen en başarılı dizayn konseptinin seçilmesinde kullanılmıştır. Performans testlerinin sonuçları da sunulmuştur.

AnahtarKelimeler: Konteyner, Sidelifter, Lojistik, Simulasyon, Sonlu Elemanlar Metodu

ACKNOWLEDGEMENTS

CONTENTS   **PAGE**

LIST OF TABLES

PAGE

LIST OF FIGURES   **PAGE**

LIST OF ABBREVIATIONS AND NOMENCULATURE

TEU   **:**Twenty feet equivalent unit

PTO   **:**Power take off

FEM   **:** Finite element method

CAD   **:**Computer aided design

CAM   **:** Computer aided design

CATIA   **:**Computer Aided Three-dimensional Interactive Application

CAE   **:**Computer Aided Engineering

FEA   **:** Finite element analysis

3D   **:** Three dimensional

s_u : Tensile Strength

s_y : Yield Strength

E   : Modulus of Elasticity in Tension

s_{ys} : Yield strength in shear

s_{us} :Ultimate strength in shear

ν   :Poisson's Ratio

G   : Modulus of Elasticity in Shear

OAW   **:**Oxyacetylene welding

SMAW   **:** Shielded metal arc welding

GTAW   **:** Gas–tungsten arc welding

PAW   **:**Plasma arc welding

GMAW   **:**Gas–metal arc welding

FCAW   **:** Flux-cored arc welding

SAW   **:**Submerged arc welding

ESW   **:**Electroslag welding

EBW   **:** Electron beam welding

LBW   **:** Laser beam welding

C   : Carbon

Si   : Silicon

Mn   : Manganese

P   : Phosphorus

S   : Sulphur

Nb : Niobium

Al   : Aluminium

N   : Nitrogen

Ar   : Argon

He : Helium

CNC : Computer Numerical Control

MIG : Metal inert gas

1. INTRODUCTION

Transportation has always been strongly tied to economic development and sustainability; and regional, national or international economies have come to depend increasingly on efficient and secure transportation systems. Transportation systems connect vital regional economic components to ensure that employees can use these systems to get to work while also ensuring that businesses can use them to provide and receive various supporting services and/or supplies (Fries et al., 2009).

In today's world, Most of the supplies are transported into two types:

- Bulk shipping of huge quantities of commodities like crude oil, coal, ore, grain, etc., which are shipped using specialized vessels called bulk carriers;
- Containerized shipping in which a variety of goods are packed into standard size steel containers that are shipped on vessels (Murty et al., 2005).

Containers are large boxes, which are used to transport goods from one destination to another. The introduction of a container system shows several benefits. Some of the above mentioned benefits are saving the handling trouble, reducing the damage potential for goods and decreasing the handling costs. Such a system contributes to a positive development of the intermodal system of freight transportation which enables a simplified movement of goods (Nishimura et al., 2009). Intermodal containers have several different kind and size (Table 1.1) although values vary slightly from manufacturer to manufacturer.

Table 1.1. The most typical container types (http://en.wikipedia.org, 2010)

		20' Container	40' Container	40' High-Cube Container	45' High-Cube Container
External dimensions	Length	6,058 m	12,192 m	12,192 m	13,716 m
	Width	2,438 m	2,438 m	2,438 m	2,438 m
	Height	2,591 m	2,591 m	2,896 m	2,896 m
Interior dimensions	Length	5,710 m	12,032 m	12,000 m	13,556 m
	Width	2,352 m	2,352 m	2,311 m	2,352 m
	Height	2,385 m	2,385 m	2,650 m	2,698 m
Door aperture	Width	2,343 m	2,343 m	2,280 m	2,343 m
	Height	2,280 m	2,280 m	2,560 m	2,585 m
Volume		33,1 m³	67,5 m³	75,3 m³	86,1 m³
Maximum gross mass		30.400 kg	30.400 kg	30.848 kg	30.400 kg
Empty weight		2.200 kg	3.800 kg	3.900 kg	4.800 kg
Net load		28.200 kg	26.600 kg	26.580 kg	25.600 kg

Over the recent years, the use of containers for intercontinental maritime transport has abruptly increased. Figure 1.1 exhibits the growth of world container turnover.
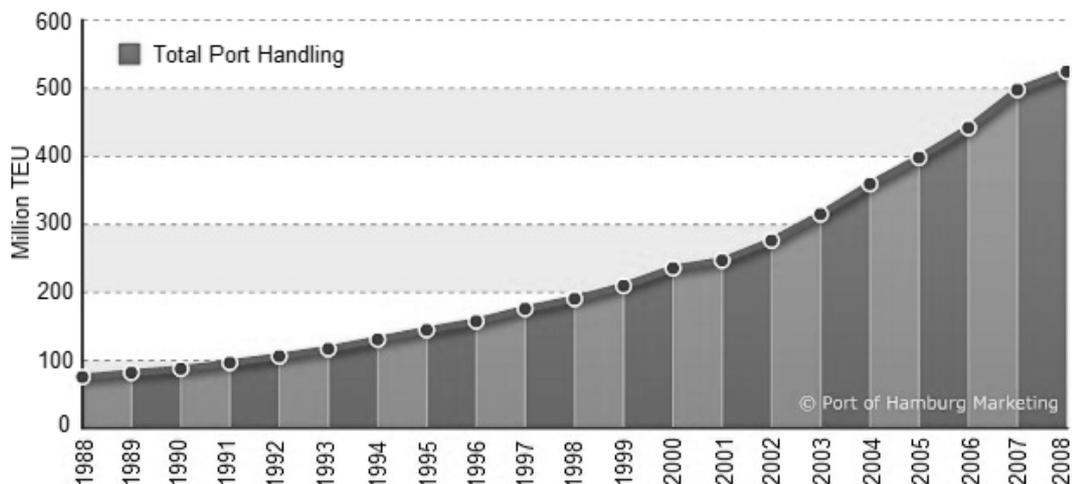
Figure 1.1. The growth of world container turnover (Anonymous, 2011a)

Starting with 80 million TEU (Twenty Feet Equivalent Unit) in 1988, world container turnover has reached more than 500 million TEU in 2008. As shown in Figure 1.2, a further continuous increase is expected in the upcoming years, especially between Asia and Europe (Kim K. H. and Günther H. O., 2007).
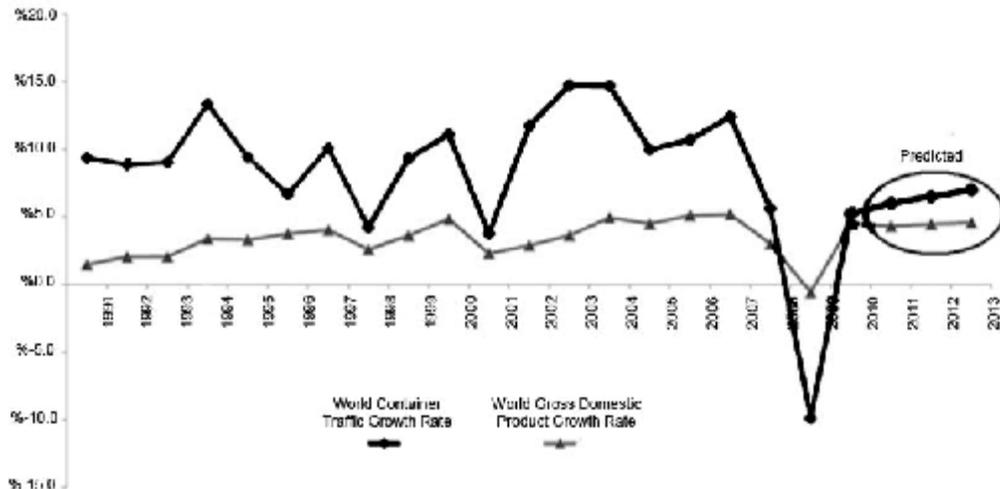
Figure 1.2. World container traffic and world gross domestic product growth rate
        (Ugurlu, 2011)

Due to the continuously increasing container trade, many terminals are currently operating at or close to maximum capacity. Most terminals in metropolitan areas cannot meet increasing demand due to limited space and inefficient operations. Increasing capacity by using additional land is often a costly proposition due to the scarcity of land or its high cost (Ioannou, 2008).

At container terminals, containers are transhipped from one mode of transportation to another. Within terminal different types of material handling equipment are used to tranship containers (Vis and Koster, 2003).Intermodal terminals are a point of interface between road and rail transport for containerized goods. Containers processed in intermodal terminals vary in length, height, weight and handling requirements. They are carried by trains consisting of a sequence of wagons which vary in length, deck height and carrying capacity. Containers are transferred to/from wagons by a variety of handling equipment such as forklifts, sidelifters, reachstackers and gantry cranes (Corry and Kozan, 2006). Advantages in

using sidelifters over conventional forklifts or reachstackers include faster travelling speeds, safer operating conditions because of clearer visibility and the ability to use available space more efficiently.

Roads and rail are currently carrying relatively small quantities of products traded internationally compared with maritime shipping, especially in terms of products moving among economic regions. However, likely increases in the total quantity of international trade will increase the amount of goods that need to be transported internationally. In addition, the relative cost and speed advantages of land based transport compared to water and air are likely to increase demand for international movements by these modes (Woodburn et al., 2010).

A sidelifter is a specialized truck or semi-trailer used to hoist and transport containers over long distances (Anonymous, 2011b). Sidelifters deliver a range of options. Operators have the ability to off load and pick up fully loaded containers, without the need to wait for other machinery to arrive or become available. This eliminates the cost associated with leaving trailers on site and increases the opportunities for the possible number of pickups and drop offs in each cycle. Using sidelifter also means that containers can also be placed anywhere the sidelifter unit is able to access, which eliminates the need for expensive ground preparation the way it's required for reachstacker operations. The sidelifter can work in conjunction with companion vehicles, improving standard container trailer utilization. Sidelifter can do the rail transfer operation and then they can double stack in adjoining depots and also shuttle containers to and from nearby exporters and importers; handling all operations without the need for reachstackers or other equipment investments. This is particularly useful in remote areas or situations where there is little infrastructure, exactly the type of areas that can benefit most from intermodal containerization (Anonymous, 2007).

Customers focused mainly on low total systems cost, high quality and good delivery performance. Now they also expect short product life cycles and time to market, innovativeness and customization. On the other hand, companies and their suppliers are experiencing the emergence of a global economy and rapidly changing markets. At the same time, the complexity of products and technologies is increasing

and their functionalities are expanding (Momme and Hvolby, 2002). The means by which industries strengthen and enhance supply chain efficiency and decrease logistics management costs are critical factors for economic development and serve as reference models for transferring technologies to developing economies (Trappey et al., in press).

Among many others, sidelifters are one of the imported equipment from foreign countries. By developing and manufacturing this equipment in Turkey, the amount of the imported machines is reduced and less unemployment can be obtained. Sidelifters generally have the following attributes:

- The hydraulically powered cranes lift the container (from the ground, loading dock, another vehicle, railway wagon or from the top of another container placed on the ground or other location) on and off the chassis. These cranes are placed on top of the sidelifter chassis and they are normally able to travel along the chassis being shifted by hydraulic cylinders or hydraulic motors in order to load varying container lengths.

- Typically the cranes are powered by a trailer mounted diesel engine or gasoline engine, the cranes are sometimes powered via a Power Take Off (PTO) from the truck or tractor.

- Stabilizing legs of sidelifter are fitted with hydraulic legs which are necessary to permit the lifting of up to 40 tonnes loads without tilting the vehicle. These may be adjustable to assist operation on unlevel ground and facilitate greater safety margins and load limits when stacking containers.

- Chains are attached from the top of the cranes to the corner castings at the base of the container during lifting operations. There is a special linking device that when placed between two 6,096 m containers allow the user to lock two 6,096 m containers together allowing the container lifter to lift them as if they were a 12,192 m container.

- The tractor or cab, which pulls the trailer and in some cases supplies power through the PTO. This tractor or cab always supplies the compressed air for the wheels' brakes of the sidelifter. Normally, the sidelifter cannot be operated without being connected to the tractor. Even if the power pack is

under the sidelifter, the tractor provides compressed air for the trailer brakes and also additional stability for the lifting operation.

- The chassis bears the weight of the container when loaded and also supports the cranes.

- The remote control, which is a device with joysticks and buttons typically attached via a multi pair electric wire or via a radio signal, allows the operator to walk around the container and view the unit from various different angles during operation. In disaster sites, the remote control of construction machines is essential in order to minimize the injuries and loss of life. There is a substantial literature dealing with the development of remote control systems for manipulating the functional tasks of construction machines in disaster sites (Sasaki and Kawashima, 2008).

In addition to controlling the raising and lowering of the cranes, the operator can sometimes tilt the chassis using the stabilizing legs which provides a limited ability to operate on non-level ground. Some sidelifters have a telescopic chassis, sometimes called trombone chassis, allowing the unit to expand and contract in order to accommodate containers. Trombone units are especially suited for small secondary roads where cornering is quite difficult with 12,192 m trailers (Anonymous, 2011b).

Over the recent years, the use of containers has dramatically increased. As a result of this, the importance of practical container handling equipment has also grown. For handling and transporting containers, there can be used different types of mechanical machines. They primarily differ by their degree of automation and performance figures. In this study, as an answer for the above mentioned necessity for handling containers, a sidelifter prototype is designed and manufactured. The objective of the sidelifter prototype is;

- Using national sources
- Operational safety
- Easy and economic use
- Ability to load and unload ISO stardard containers
- Long operational life

2. PRELIMINARY WORK

The sidelifter was invented in the 1960s for military operations. Today, all over the World, just 2 big companies are manufacturing sidelifters. In a containerized world, there is an obvious demand for a loader which makes it possible to load at one destination, carry and unload at other destination by itself. Also in the literature, there is not presented study about sidelifters, but some studies show interested with the moving machines such as backhoe-loader, bucket wheel excavator, excavator etc.

Karlinski et al. used finite element method to analyse protective structures for construction and mining machine operators (Karlinski et al., 2008).

Rusinski et al. discussed designing problems of machines used in underground mining and investigation of its reasons based on cracked boom of underground mine machine. Numerical and experimental approaches were used in order to achieve wider point of view of such accidents, which happens in this type of machines.Numerical method used for the finite element method (Rusinski et al., 2006).

Miralbes and Castejon presented a new methodology of calculation by means of the FEM applied to crane jibs. This analysis has been carried out in terms of strength, stiffness and for any type of crane jib such as telescopic crane, lattice crane, closed beam crane, etc. The principal conclusions that are it has been developed a methodology for the design, calculation and optimization of crane jibs for forklift trucks, adapting the regulation UNE-58536 for mobile cranes (Miralbes and Castejon, 2009).

Sasaki and Kawashima developed remote control of backhoe at construction sites with a pneumatic robotic system. The system mainly consists of robot arm module having 2 DOFs, a control box to make the system compact and a vision system to help the task. The high portability was realized since the weight of the system is only 40 kg. The remote control system was applied with two types of backhoe, one small with bucket size of $0,025 \ m^3$ and another medium-sized with $0,28 \ m^3$. The remote control experiments were successfully conducted with support of vision from the cameras. The remote control operations were well achieved at a

construction site with the medium sized backhoe. The working efficiency of the remote operation was more than 50% compared with the direct operation. The system herein provides an opportunity to improve safety (Sasaki and Kawashima, 2008).

Ghigliazza and Holmes described the derivation and analysis of equations governing the Dynamics of a spherical pendulum with a horizontally moving support, which model the behaviours of tower or ceiling mounted cranes with rotating booms. The resulting two degree of freedom system is in general non-integrable and appears to display chaotic dynamics. They focussed on the special cases of a linearly translating suspension point and a suspension point in uniform circular motion. In the former case, the system remains completely integrable, although neither energy nor the Hamiltonian are conserved. In the second case the Hamiltonian is conserved, but there is no analogue of angular momentum conservation and while we are able to find steady coning motions and determine their stability and bifurcations, we cannot give a complete global description of the dynamics (Ghigliazza and Holmes, 2002).

3. DESIGN AND MANUFACTURING PROCESSES

In this study, CAD and FEM softwares are frequently used for the decision of the design, material and joining process. In this chapter basic information about these technologies are presented.

3.1. Computer Aided Design (CAD)

CAD/CAM products are one of the precious items for today's companies which are try to get bigger or survive in a harsh market competition. With the aid of these kind of softwares, development process allowing improved quality, reduced cost products to get to market faster.

Graphic interfaces are often used to help in the creation and manipulation of the geometrical objects. Numerous Computer Aided Design (CAD) software packages are used for engineering design which can produce files containing the geometry of the designed engineering system. These files can usually be read in by modelling software packages, which can significantly save time when creating the geometry of the models. However, in many cases, complex objects read directly from a CAD file may need to be modified and simplified before performing meshing or discretization. CAD packages are incorporate modelling and simulation packages, and these are useful for the rapid prototyping of new products (Liu and Quek, 2003).

Solid modelling systems usually provide an interface to one or more Finite Element Analysis (FEA) programs and allow direct transfer of the model's geometry to the FEA package for stress, vibration, and heat transfer analysis. Some CAD systems include a mesh generation feature which creates the FEA mesh automatically before sending the data to the FEA software. This combination of tools provides an extremely powerful means to obtain superior designs whose stresses are more accurately known than would be possible by conventional analysis techniques when the geometry is complex (Norton, 2006).

CATIA (Computer Aided Three-dimensional Interactive Application) is multi-platform CAD/CAM/CAE commercial software developed by the French

company DassaultSystèmes and marketed worldwide by IBM. Written in the C++ programming language, CATIA is the cornerstone of the DassaultSystèmes product lifecycle management software. The software was created in the late 1970s and early 1980s to develop Dassault's Mirage fighter jet, and then was adopted in the aerospace, automotive, shipbuilding, and other industries (Anonymous, 2011a).

SolidWorks is a 3D mechanical CAD (computer aided design) program that runs on Microsoft Windows and is being developed by DassaultSystèmesSolidWorks Corporation. SolidWorks is currently used by over 1.3 million engineers and designers at more than 130,000 companies worldwide.

SolidWorks application was first introduced in 1995. SolidWorks was founded in 1993 by Jon Hirschtick, who recruited a team of engineers to build a company that developed 3D CAD software that was easy to use, affordable and available on the desktop and released its first product, SolidWorks 95, in 1995. In 1997 DassaultSystèmes, best known for its CATIA CAD software, acquired the company and currently owns 100% of its shares (Anonymous, 2011b).

3.2. Finite Element Method (FEM)

The use of numerical methods such as FEA has been adopted in solving complicated geometric problems, for which it is very difficult to achieve an analytical solution. FEA is a technique for obtaining a solution to a complex mechanics problem by dividing the problem domain into a collection of much smaller and simpler domains (elements) where field variables can be interpolated using shape functions. An overall approximated solution to the original problem is determined based on variation principles. In other words, FEA is a method whereby, instead of seeking a solution function for the entire domain, it formulates solution functions for each finite element and combines them properly to obtain a solution to the whole body. A mesh is needed in FEA to divide the whole domain into small elements. The process of creating the mesh, elements, their respective nodes, and defining boundary conditions is termed discretization of the problem domain (Geng et al., 2008).

A three-dimensional (3D) solid element can be considered to be the most general of all solid finite elements because all the field variables are dependent of x, y and z. A 3D solid can also have any arbitrary shape, material properties and boundary conditions in space. As such, there are altogether six possible stress components, three normal and three shear, that need to be taken into consideration. Typically, a 3D solid element can be a tetrahedron or hexahedron in shape with either flat or curved surfaces. Each node of the element will have three translational degrees of freedom. The element can thus deform in all three directions in space. The elements are interconnected at so called nodes (Liu and Quek, 2003).

Over the past 20-30 years finite element analysis (FEA) has evolved hand in hand with the ever increasing hardware capabilities. Even with fully automatic mesh generators, there are many cases where the solution time can be less than the meshing time. The solution stage is predominantly batch oriented with little or no user interaction required, while the model preparation and meshing stage is still largely interactive. The demands placed on today's industrial automatic mesh generators are as diverse as they are great. The following is a list of some of the most important requirements on industrial meshing:

1. Basic Functionality;

2. Robustness/Reliability/Dependability;

3. Mesh Quality

4. Speed;

5. Minimal Required User Interaction:

6. Controllability

While all of these are important, when evaluating algorithms and overall meshing schemes to address this list, these requirements are often competing and a balance must be struck that best meets the user's requirements (Canann et al., 1997). Mesh generation is one of the most critical aspects of engineering simulation. Too many cells may result in long solver runs and too few many result in inaccurate results. After an FE solution is obtained, its accuracy should be checked.

Two factors determine the accuracy of a solution.

     1. Continuity of variables across element borders

     2. Magnitude of numerical error

The accuracy depends on the number of degrees of freedom. The methods to increase the accuracy are:

     1. The mesh is locally refined by reducing the size of elements, while their shape functions, i.e., the interpolating polynomials, stay unchanged (h–method). The number of elements and nodes is increased, enlarging the number of degrees of freedom. Property h, shown in Figure 3.1, denotes a characteristic dimension of the element.

     2. The number of degrees of freedom is increased by adding mid-side nodes without changing the element size. The order of shape functions is increased.

     3. The number of degrees of freedom is increased by adding displacement derivatives at the nodes while number of nodes and the shape and size of elements remain the same (p–method, shown in Figure 3.1). The order of shape functions is increased, so derived shape functions become hierarchical functions (Zahavi and Barlam, 2001).
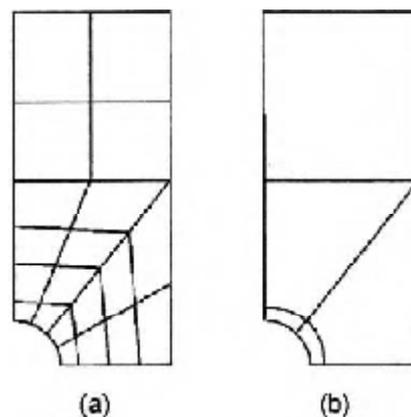
Figure 3.1. (a) h-adaptivity method and (b) p-adaptivity method (Zahavi and Barlam, 2001)

3.2.1. The Four Node Tetrahedral Element

The four node tetrahedral element (shown in Figure 3.2) is the simplest three dimensional elements used in the analysis of solid mechanics problems. This element has four nodes with each node having three translational degrees of freedom in the nodal x-y-z directions (Moaveni, 2008).
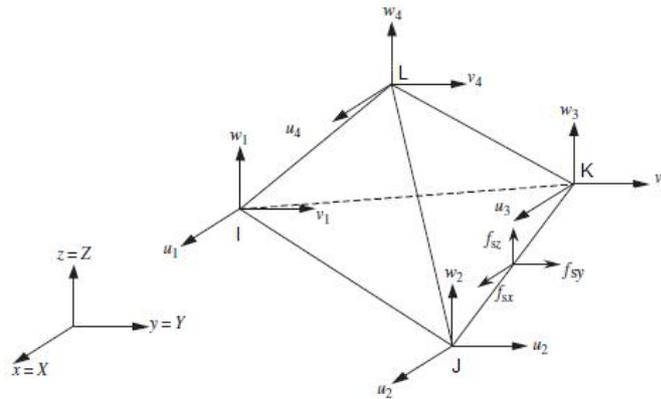
Figure 3.2. A four node tetrahedral element (Liu and Quek, 2003)

The displacement field represented by the following equations:

$$u = C_{11} + C_{12}X + C_{13}Y + C_{14}Z$$
$$v = C_{21} + C_{22}X + C_{23}Y + C_{24}Z \qquad (3.1.)$$
$$w = C_{31} + C_{32}X + C_{33}Y + C_{34}Z$$

Considering the nodal displacements, the following conditions must be satisfied

$$u = u_I \text{ at } \quad X = X_I \quad Y = Y_I \quad Z = Z_I$$
$$u = u_J \text{ at } \quad X = X_J \quad Y = Y_J \quad Z = Z_J \qquad (3.2.)$$
$$u = u_K \text{ at } \quad X = X_K \quad Y = Y_K \quad Z = Z_K$$
$$u = u_L \text{ at } \quad X = X_L \quad Y = Y_L \quad Z = Z_L$$

Similarly, other following must be satisfied

$$v = v_I \text{at} \quad X = X_I \quad Y = Y_I \quad Z = Z_I \tag{3.3.}$$

.   .   .   .   .

Substitution of respective nodal values into Eq. (1) results in 12 equations and 12 unknowns

$$u_I = C_{11} + C_{12}X_I + C_{13}Y_I + C_{14}Z_I$$
$$u_J = C_{11} + C_{12}X_J + C_{13}Y_J + C_{14}Z_J \tag{3.4.}$$
.

.

$$w_L = C_{31} + C_{32}X_L + C_{33}Y_L + C_{34}Z_L$$

Solving for the unknown C-coefficients, substituting the results back into Eq. (1) and regrouping the parameters

$$u = S_1u_I + S_2u_J + S_3u_K + S_4u_L$$
$$v = S_1v_I + S_2v_J + S_3v_K + S_4v_L \tag{3.5.}$$
$$w = S_1w_I + S_2w_J + S_3w_K + S_4w_L$$

The shape functions are;

$$S_1 = (a_I + b_IX + c_IY + d_IZ) / 6V$$
$$S_2 = (a_J + b_JX + c_JY + d_JZ) / 6V \tag{3.6.}$$
$$S_3 = (a_K + b_KX + c_KY + d_KZ) / 6V$$
$$S_4 = (a_L + b_LX + c_LY + d_LZ) / 6V$$

3.2.2. The Eight Node Brick Element (Hexahedron Element)

The eight node brick element (shown in Figure 3.3) is a simple three dimensional element used in the analysis of solid mechanics problems. Each of the eight nodes of this element has three translational degrees of freedom in the nodal x-y-z directions (Moaveni, 2008).
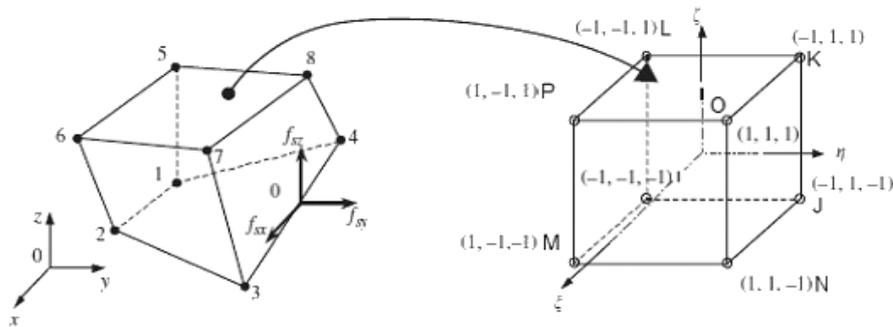
Figure 3.3. An eight nodal hexahedron element and the coordinate systems (Liu and Quek, 2003)

$$u = (u_I(1 - s)(1 - t)(1 - r) + u_J(1 + s)(1 - t)(1 - r)) / 8$$

$$+ (u_K(1 + s)(1 + t)(1 - r) + u_L(1 - s)(1 + t)(1 - r)) / 8$$

$$+ (u_M(1 - s)(1 - t)(1 + r) + u_N(1 + s)(1 - t)(1 + r)) / 8$$

$$+ (u_O(1 + s)(1 + t)(1 + r) + u_p (1 - s)(1 + t)(1 + r)) / 8$$

$$v = (v_I(1 - s)(1 - t)(1 - r) + v_J(1 + s)(1 - t)(1 - r)) / 8$$

$$+ (v_K(1 + s)(1 + t)(1 - r) + v_L(1 - s)(1 + t)(1 - r)) / 8 \qquad (3.7.)$$

$$+ (v_M(1 - s)(1 - t)(1 + r) + v_N(1 + s)(1 - t)(1 + r)) / 8$$

$$+ (v_O(1 + s)(1 + t)(1 + r) + v_p(1 - s)(1 + t)(1 + r)) / 8$$

$$w = (w_I(1 - s)(1 - t)(1 - r) + w_J(1 + s)(1 - t)(1 - r)) / 8$$

$$+ (w_K(1 + s)(1 + t)(1 - r) + w_L(1 - s)(1 + t)(1 - r)) / 8$$

$$+ (w_M(1 - s)(1 - t)(1 + r) + w_N(1 + s)(1 - t)(1 + r)) / 8$$

$$+ (w_O(1 + s)(1 + t)(1 + r) + w_p(1 - s)(1 + t)(1 + r)) / 8$$

3.2.3. The Ten Node Tetrahedral Element

The ten node tetrahedral element (shown in Figure 3.4) is a higher order version of the three dimensional linear tetrahedral element. When compared to the four node tetrahedral element, the ten node tetrahedral element is better suited for and more accurate in modelling problems with curved boundaries (Moaveni, 2008).
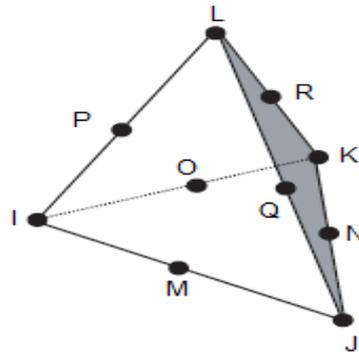
Figure 3.4. A ten node tetrahedral element (Liu and Quek, 2003)

$$u = u_I(2S_1\text{-}1)S_1 + u_J(2S_2 - 1)S_2 + u_K(2S_3\text{-}1)S_3 + u_L(2S_4 - 1)S_4$$
$$+ 4(u_M S_1 S_2 + u_N S_2 S_3 + u_O S_1 S_3 + u_P S_1 S_4 + u_Q S_2 S_4 + u_R S_3 S_4)$$
$$v = v_I(2S_1\text{-}1)S_1 + v_J(2S_2 - 1)S_2 + v_K(2S_3\text{-}1)S_3 + v_L(2S_4 - 1)S_4$$
$$+ 4(v_M S_1 S_2 + v_N S_2 S_3 + v_O S_1 S_3 + v_P S_1 S_4 + v_Q S_2 S_4 + v_R S_3 S_4) \qquad (3.8.)$$
$$w = w_I(2S_1\text{-}1)S_1 + w_J(2S_2 - 1)S_2 + w_K(2S_3\text{-}1)S_3 + w_L(2S_4 - 1)S_4$$
$$+ 4(w_M S_1 S_2 + w_N S_2 S_3 + w_O S_1 S_3 + w_P S_1 S_4 + w_Q S_2 S_4 + w_R S_3 S_4)$$

3.2.4. The Twenty Node Brick Element

The twenty node brick (shown in Figure 3.5) is a higher order version of the three dimensional eight node brick element. This element is more capable and more accurate for modelling problems with curved boundaries than the eight node brick element (Moaveni, 2008).
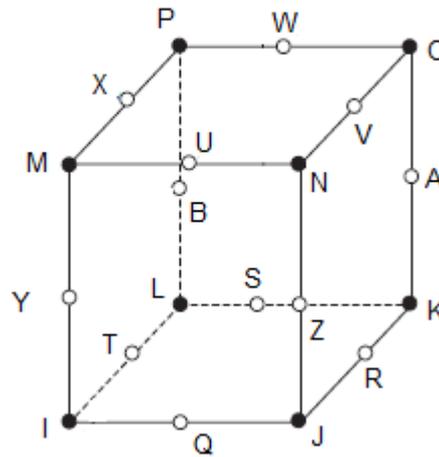
Figure 3.5. A twenty node brick element (Liu and Quek, 2003)

$$
\begin{aligned}
u = & (u_I(1 - s)(1 - t)(1 - r)(- s - t - r - 2) + u_J(1 + s)(1 - t)(1 - r)(s - t - r - 2))/8 \\
& + (u_K(1 + s)(1 + t)(1 - r)(s + t - r - 2) + u_L(1 - s)(1 + t)(1 - r)(- s + t - r - 2))/8 \\
& + (u_M(1 - s)(1 - t)(1 + r)(- s - t + r - 2) + u_J(1 + s)(1 - t)(1 + r)(s - t + r - 2))/8 \\
& + (u_O(1 + s)(1 + t)(1 + r)(s + t + r - 2) + u_P(1 - s)(1 + t)(1 + r)(- s + t + r - 2))/8 \\
& + (u_Q(1 - s^2)(1 - t)(1 - r) + u_R(1 + s)(1 - t^2)(1 - r))/4 \\
& + (u_S(1 - s^2)(1 + t)(1 - r) + u_T(1 - s)(1 - t^2)(1 - r))/4 \qquad\qquad (3.9.) \\
& + (u_U(1 - s^2)(1 - t)(1 + r) + u_V(1 + s)(1 - t^2)(1 + r))/4 \\
& + (u_W(1 - s^2)(1 + t)(1 + r) + u_X(1 - s)(1 - t^2)(1 + r))/4 \\
& + (u_Y(1 - s)(1 - t)(1 - r^2) + u_Z(1 + s)(1 - t)(1 - r^2))/4 \\
& + (u_A(1 + s)(1 + t)(1 - r^2) + u_B(1 - s)(1 + t)(1 - r^2))/4
\end{aligned}
$$

The v- and w- components of the displacement are similar to the u-component.

3.3. Properties of Steel

Steel is an efficient material for structural purposes because of its good strength to weight ratio. Steel can be supplied with strength levels from about $250N/mm^2$ up to about $2000N/mm^2$ for common structural applications, although the strength requirements may limit the product form. The major advantage of steel is its high strength relative to the strengths of the other common structural materials: wood, masonry, and concrete (Davison and Graham, 2003). Unlike masonry and concrete, which are weak in tension, steel is strong in both tension and compression. Because of its high strength, structural steel is widely used in construction. The tallest and longest span structures are predominantly steel (Rokach, 1991).

Steel derives its mechanical properties from a combination of chemical composition, heat treatment and manufacturing processes. While the major constituent of steel is always iron the addition of very small quantities of other elements can have a marked effect upon the type and properties of steel. These elements also produce a different response when the material is subjected to heat treatments involving cooling at a prescribed rate from a particular peak temperature. The manufacturing process may involve combinations of heat treatment and mechanical working which are of critical importance in understanding the subsequent performance of steels. The effects of chemical composition and heat treatment on the metallurgy and properties of steels are to recognize that the properties depend upon the following factors:

1. Microstructure
2. Grain size
3. Non-metallic inclusions
4. Precipitates within grains or at grain boundaries
5. The presence of absorbed or dissolved gases.

Steel is basically iron with the addition of small amounts of carbon up to a maximum of 1.67% by weight, and other elements added to provide particular mechanical properties. Above 1.67% carbon the material generally takes the form of cast iron. As the carbon level is increased, the effect is to raise the strength level, but

reduce the ductility and make the material more sensitive to heat treatment. The cheapest and simplest form is therefore a plain carbon steel commonly supplied for the steel reinforcement in reinforced concrete structures, for wire ropes, for some general engineering applications in the form of bars or rods, and for some sheet/strip applications. However, plain carbon steels at medium to high carbon levels give rise to problems where subsequent fabrication/manufacturing takes place, particularly where welding is involved, and more versatility can be obtained by keeping carbon to a relatively low level and adding other elements in small amounts. When combined with appropriate heat treatments, addition of these other elements produces higher strength while retaining good ductility, fracture toughness, and weldability, or the development of improved hot strength, or improved corrosion resistance. The retention of good fracture toughness with increased strength is particularly important for thick sections, and for service applications at low temperatures where brittle fracture may be a problem. Hot strength is important for service applications at high temperatures such as pressure vessels and piping in the power generation and chemical process plant industries. Corrosion-resistance is important for any structures exposed to the environment, particularly for structures immersed in sea water. Weathering grades of steel are designed to develop a tight adherent oxide layer which slows down and stifles continuing corrosion under normal atmospheric exposure of alternate wet and dry conditions. Stainless steels are designed to have a protective oxide surface layer which reforms if any damage takes place to the surface, and these steels are therefore designed not to corrode under oxidizing conditions. Stainless steels find particular application in the chemical industry (Davison and Graham, 2003).

Mechanical properties should be taken in consideration for the material selection (Figure 3.6), these are;

- Tensile Strength (s_u):The peak of the stress-strain curve is called as ultimate tensile strength (s_u) or simply the tensile strength. At this point during the test, the highest apparent stress on a test bar of the material is measured.

- Yield Strength (s_y):That portion of the stress-strain diagram where there is a large increase in strain with little or no increase in stress is called the yield strength

(s_y). This property indicates that the material yielded or elongated plastically, permanently and to a large degree.
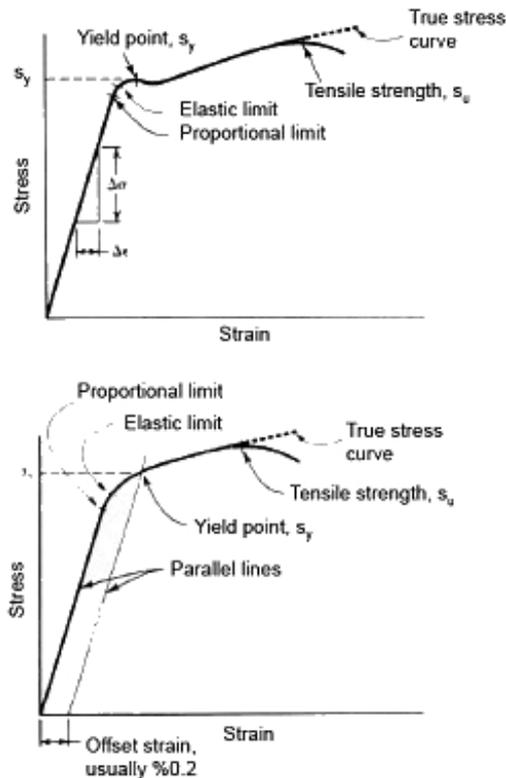
Figure 3.6. Typical stress-strain diagram for steel and aluminium (Mott, 2004)

* Proportional Limit:That point on the stress-strain curve where it deviates from a straight line is called the proportional limit. At or above that stress value, stress is no longer proportional tostrain. Below the proportional limit, Hooke's law applies. According to this law stress is proportional to strain. Inmechanical design, materials are rarely used at stresses above the proportional limit.

* Elastic Limit:At some point a material experiences some amount of plastic strain and thus will not return to its original shape after release of the load. Below that level, the material behaves completely elastically. The proportional limit and the elastic limit lie quite close to the yield strength, because they are difficult to determine.

* Modulus of Elasticity in Tension (E):For the part of the stress-strain diagram that is straight, stress is proportional to strain, and the value of E, the modulus of

elasticity is the constant of proportionality. The modulus of elasticity indicates the stiffness of the material or its resistance to deformation.

- Ductility and Percent Elongation:Ductility is the degree to which a material will deform before ultimate fracture. The opposite of ductility is brittleness. When ductile materials are used in machine members, impending failure is detected easily and sudden failure is unlikely. Also, ductile materials normally resist the repeated loads on machine elements better than brittle materials. The usual measure of ductility is the percent elongation of the material after fracture in a standard tensile test.

- Shear Strength (s_{ys} and s_{us}):Both the yield strength and the ultimate strength in shear (s_{ys} and s_{us}, respectively) are important properties of materials. The following estimates are generally used;

$$s_{ys} = s_y/2 \ = 0,50*s_y = \text{Yield strength in shear} \qquad\qquad (3.10.)$$

$$s_{us} = 0,75*s_u \qquad\quad = \text{Ultimate strength in shear} \qquad\qquad (3.11.)$$

- Poisson's Ratio (ν):When a material is subjected to a tensile strain, there is a simultaneous shortening of the cross-sectional dimensions perpendicular to the direction of the tensile strain. The ratio of the shortening strain to the tensile strain is called Poisson's ratio.

- Modulus of Elasticity in Shear (G):The modulus of elasticity in shear (G) is the ratio of shearing stress to shearing strain. This property indicates material's stiffness under shear loading (Mott, 2004).

- Hardness:Hardness is the property of a metal, which gives it the ability to resist being permanently deformed (bent, broken, or have its shape changed), when a load is applied. The greater the hardness of the metal, the greater resistance it has to deformation.

- Machinability:Machinability is related to the ease with which a material can be machined to a good surface finish with reasonable tool life. Production rates are directly affected by machinability (Mott, 2004).

- Toughness and Impact Resistance:The ability per unit volume without fracture of a material to absorb energy is called as toughness, also called as modulus of toughness. It is equal to the area under the stress-strain curve up to the fracture point.

The stress-strain test is done at very low, controlled strain rates, allowing the material to accommodate itself to the changing load. If the load suddenly applied, the energy absorption capacity of the material becomes important. The energy in the differential element is its strain energy density, or the area under the stress-strain curve at any particular strain (Norton, 2006).

$$U_0 = \int_0^e s\,de \qquad \text{(3.12.)}$$

Fatigue Strength and Endurance Strength:Parts subjected to repeated applications of loads or to stress conditions that vary with time over several thousands or millions of cycles fail because of the phenomenon of fatigue. Materials are tested under controlled cyclic loading to determine their ability to resist such repeated loads. The resulting data are reported as the fatigue strength, also called the endurance strength of the material.

- Creep: When materials are subjected to high loads continuously, they may experience progressive elongation over time. This property should be considered for metals operating at high temperatures.

3.4. Fusion Welding Processes

Fusion welding is a joining process that uses fusion of the base metal to make the weld. The three major types of fusion welding processes are as follows:

Gas welding:

Oxyacetylene welding (OAW)

Arc welding:

Shielded metal arc welding (SMAW)

Gas–tungsten arc welding (GTAW)

Plasma arc welding (PAW)

Gas–metal arc welding (GMAW)

Flux-cored arc welding (FCAW)

Submerged arc welding (SAW)

Electroslag welding (ESW)

High-energy beam welding:

Electron beam welding (EBW)

Laser beam welding (LBW)

Since there is no arc involved in the electroslag welding process, it is not exactly an arc welding process. For convenience of discussion, it is grouped with arc welding processes.

Table 3.1 shows the fusion welding processes recommended for carbon steels, low-alloy steels, stainless steels, cast irons, and aluminium alloys (Process code: SMAW, shielded metal arc welding; SAW, submerged arc welding; GMAW, gas–metal arc welding; FCAW, flux-cored arc welding; GTAW, gas–tungsten arc welding; PAW, plasma arc welding; ESW, electroslag welding; OFW, oxyfuel gas welding; EBW, electron beam welding; LBW, laser beam welding. *b* Abbreviations: S, sheet, up to 3mm (1/8 in.); I, intermediate, 3–6mm (1/8–1/4 in.); M, medium, 6–19mm (1/4–3/4 in.); T, thick, 19mm (3/4 in.) and up; X, recommended).

Table 3.1. The fusion welding processes recommended for carbon steels, low-alloy steels, stainless steels, cast irons, and aluminium alloys (Kou, 2003)

Material	Thickness	SMAW	SAW	GMAW	FCAW	GTAW	PAW	ESW	OFW	EBW	LBW
Carbon steels	S	×	×	×		×			×	×	×
	I	×	×	×	×	×			×	×	×
	M	×	×	×	×			×	×	×	×
	T	×	×	×	×				×	×	
Low-alloy steels	S	×	×	×		×			×	×	×
	I	×	×	×	×	×				×	×
	M	×	×	×	×			×		×	×
	T	×	×	×	×					×	
Stainless steels	S	×	×	×		×	×		×	×	×
	I	×	×	×	×	×	×			×	×
	M	×	×	×	×		×	×		×	×
	T	×	×	×	×						
Cast iron	I	×							×		
	M	×	×	×	×				×		
	T	×	×	×	×				×		
Aluminum and alloys	S			×		×			×	×	×
	I			×		×	×			×	×
	M			×		×				×	
	T			×						×	

At welding operation different types of joining processes are used, some of these are presented in Figure 3.7.
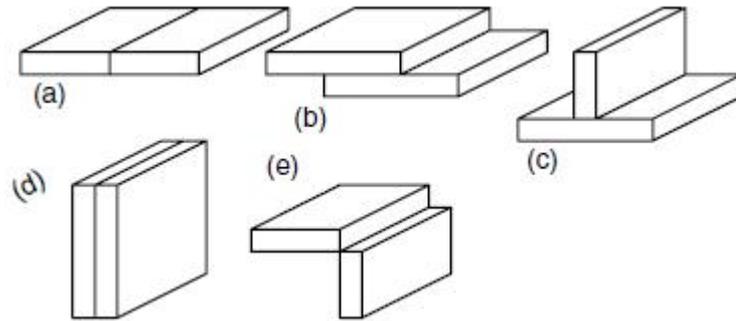
Figure 3.7. Five basic types of weld joint designs. a) butt joint b) lap joint c) T-joint d) edge joint e) corner joint (Kou, 2003)

4. MATERIAL AND METHOD

4.1. Designing of the Sidelifter

In this study, at design steps, CATIA V5 software program was used for the development of the mechanism within Çukurova University Automotive Engineering Laboratories. During the design steps different modules and workbenches of CATIA V5 software was used, these are:

Ø Mechanical Design Application Tools;

Sketcher Workbench is used for drawing sketches of the solid model (Figure 4.1).
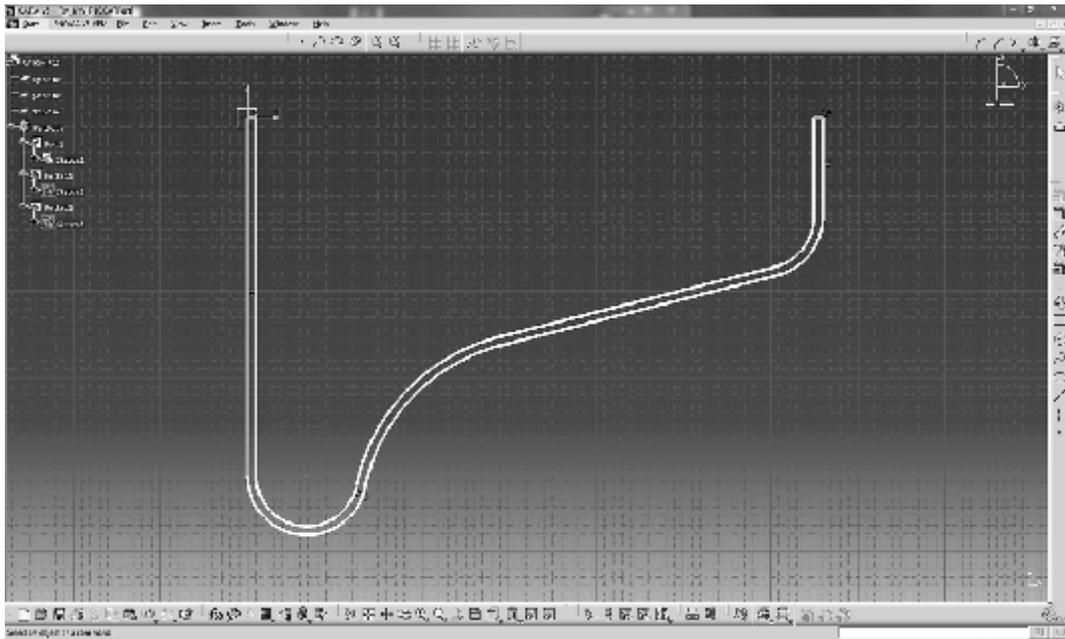
Figure 4.1. View of a sheet in CATIA V5 sketcher workbench

Part Workbench is used for the creation of three dimensional entities. Most of CATIA V5 workbenches are based on part workbench (Figure 4.2).
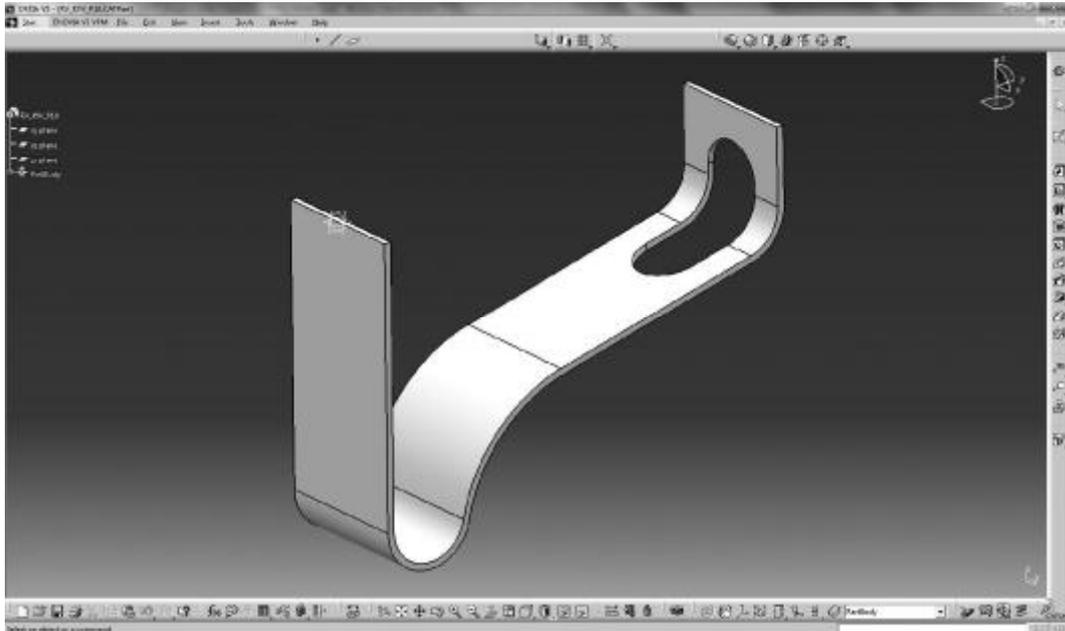
Figure 4.2. View of a sheet in CATIA V5 part workbench

Assembly modelling is used for creating designs that consist of two or more components assembled together at their respective work positions. The components are brought together and assembled in Assembly Design workbench by applying suitable parametric assembly constraints to them. The assembly constraints allow restricting the degrees of freedom of components on their respective work positions (Figure 4.3). The assembly files in CATIA V5 are called product files.
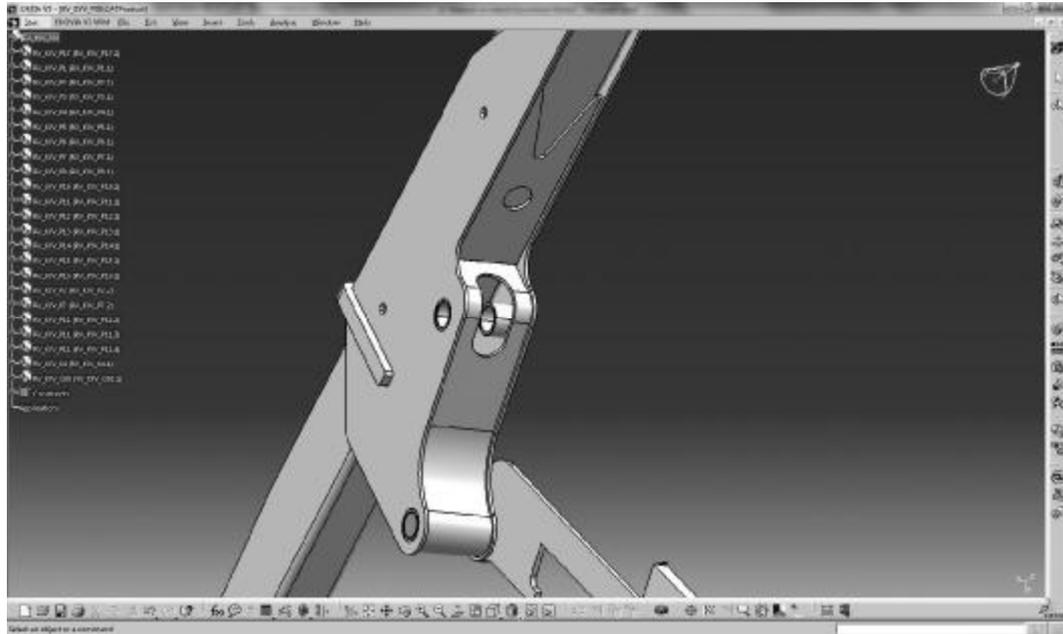
Figure 4.3. View of a subassembly in CATIA V5 assembly workbench

Ø Infrastructure Application Tools;

Real Time Rendering Workbench is used for the tools of light create, environments, turn tables and simulations for picture and video renderings of the CATIA V5 products (Figure 4.4).
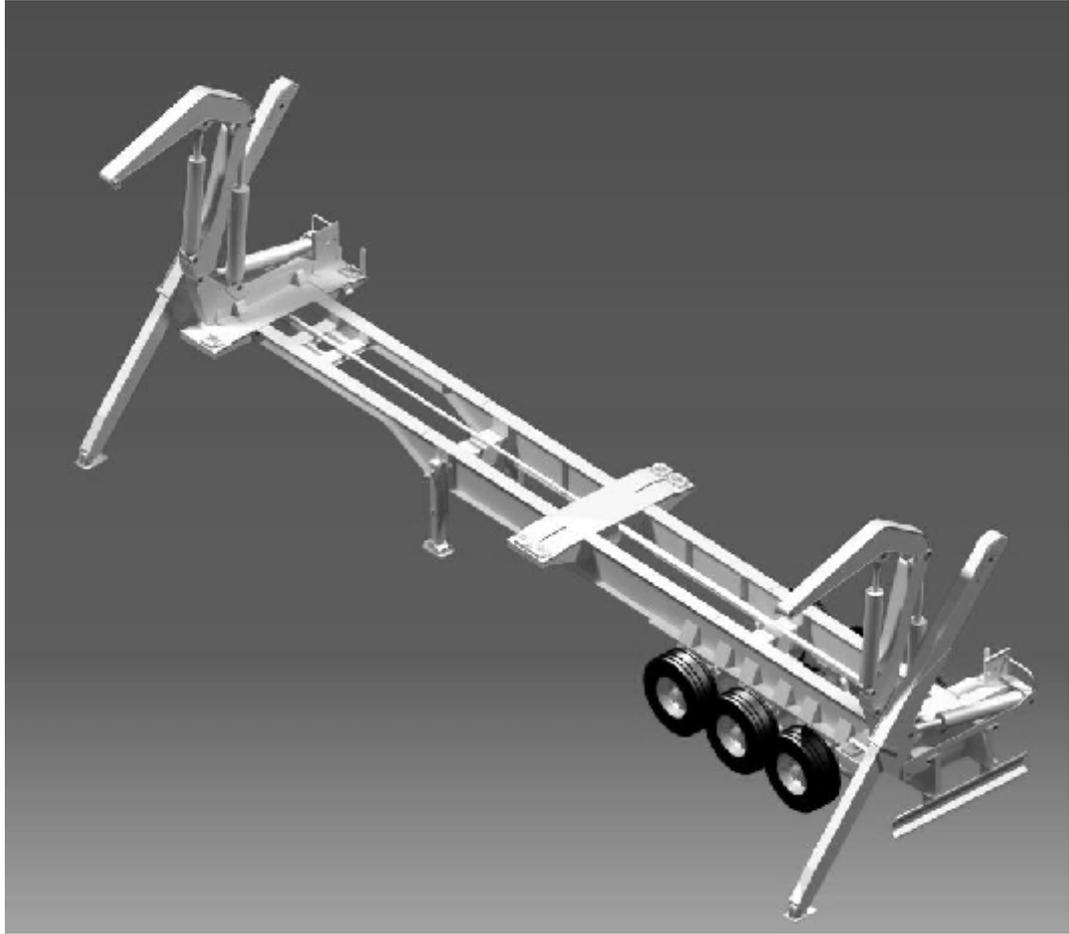
Figure 4.4. Rendered view of the sidelifter in CATIA V5

Ø Digital Mock-up Application Tools;

DMU Kinematics Workbench is provided the tools to help the user apply and extract kinematics information about a design. As shown in Figure 4.5, part intersections into assembly detected with the aid of this workbench.
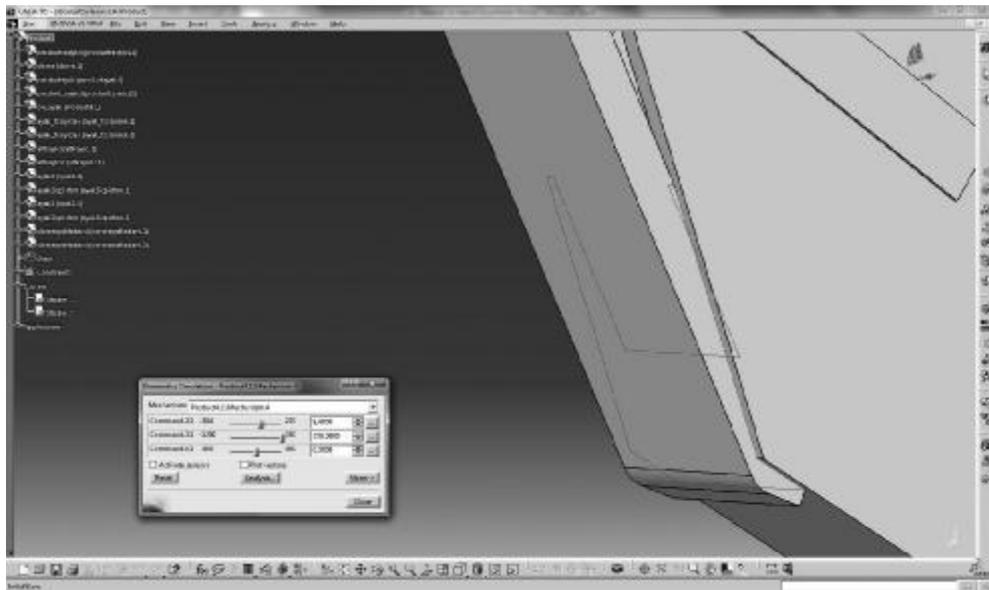
Figure 4.5. Clash detection by using DMU kinematics in CATIA V5

Solidworks software program was used for the developments of the mechanism with RAYVAG Railcar Industry and Trade S.A. Technical drawings of sidelifter mechanism were prepared with the aid of this program. Parts were prepared as sheet metal at Solidworks. By using bench, parts have been seen as fold and unfold through design steps. General view of solid modal and draft of a sheet in SolidWorkscan be seen in Figure 4.6 and Figure 4.7 respectively.
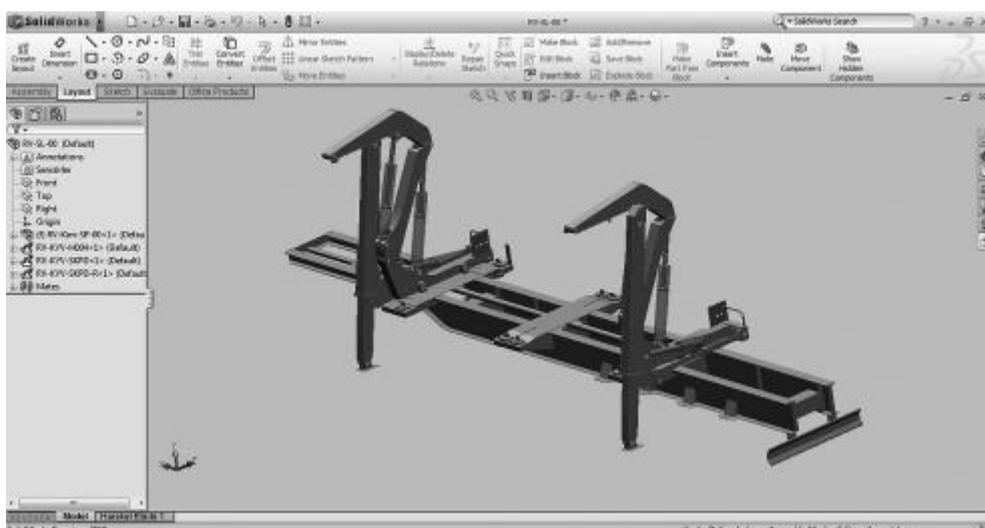
Figure 4.6. General view of solid modal in SolidWorks
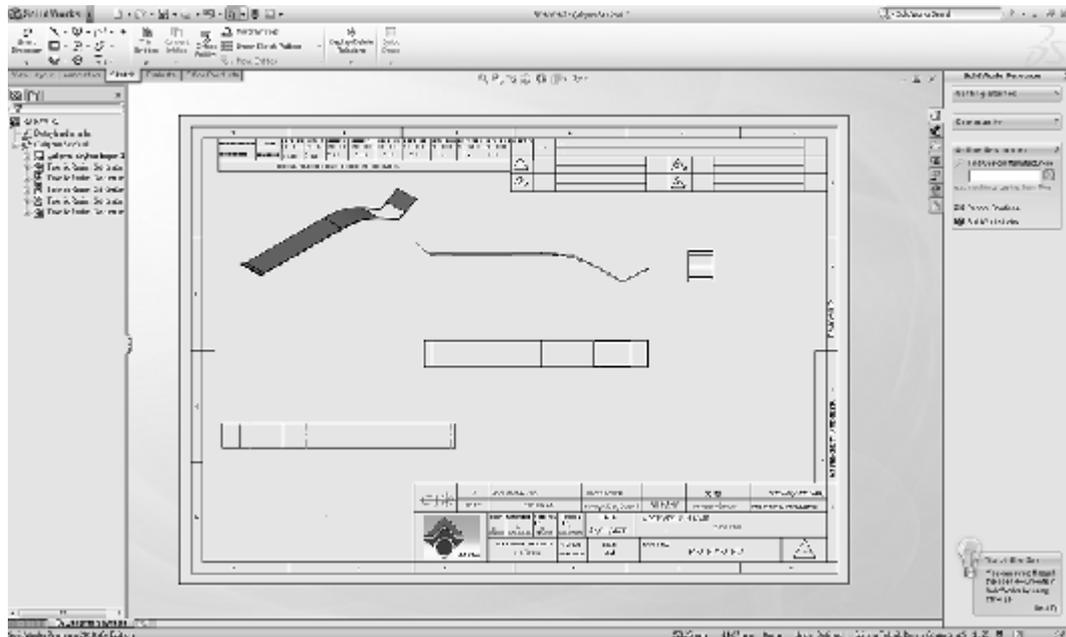
Figure 4.7. Technical drawing of a sheet in SolidWorks

General view of solid model in CATIA V5 can be seen in Figure 4.8.
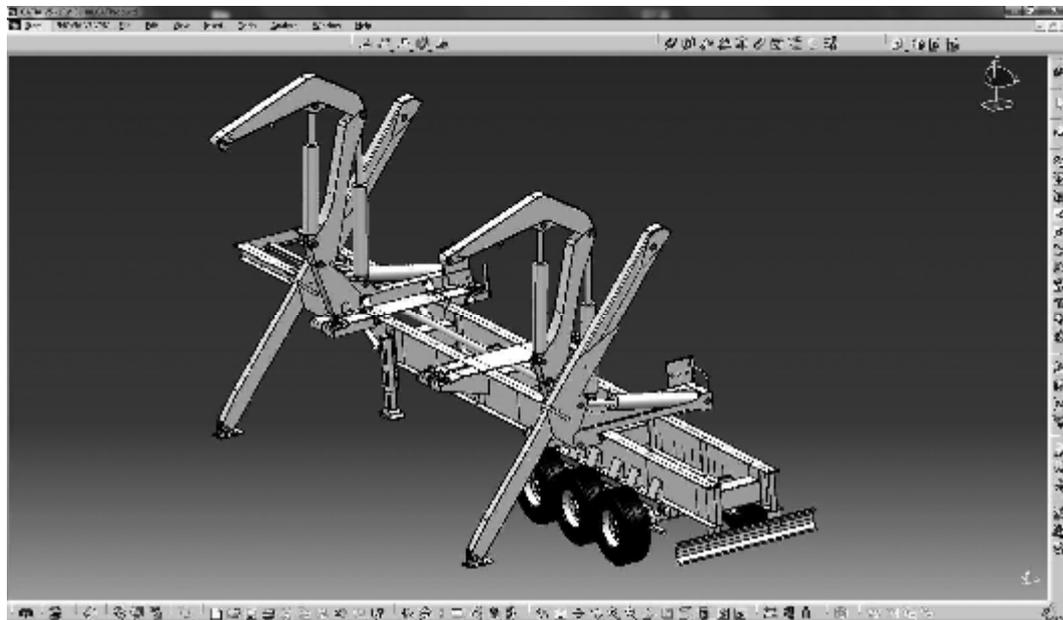
Figure 4.8. General view of solid model in CATIA V5

4.2. Finite Element Analyses

FEA software typically uses a CAD representation of the physical model. In this thesis, In order to calculate operation stresses on the prototype 2 different types of loading operation have been analysed by following the chart in Figure 4.9. Analyses are carried out in Çukurova University Automotive Engineering Laboratories with the aid of workstation, which has 2 processors (24 cores) and 32 GB RAM. Although, in practical world, heaviest container has 30.400 kg weight, in this study, 40.000 kg weight is applied at analyses for unexpected service conditions, which are;

- Distribution of 40 tonnes load on the chassis (to symbolize when the container is settle on the chassis after loading operation)
- 40 Tonnes loading from the hooks (to symbolize when the container is loading and unloading)

The following assumptions have been done in analyses;

- It is assumed that the material behaviour is linear elastic and strains are small. Therefore, linear elastic analysis will be carried out.
- Pins and links are assumed rigid.
- The loads are applied statically.
- It is also assumed that material properties of the structure are homogenous and not changed after heat treatment (welding operation).
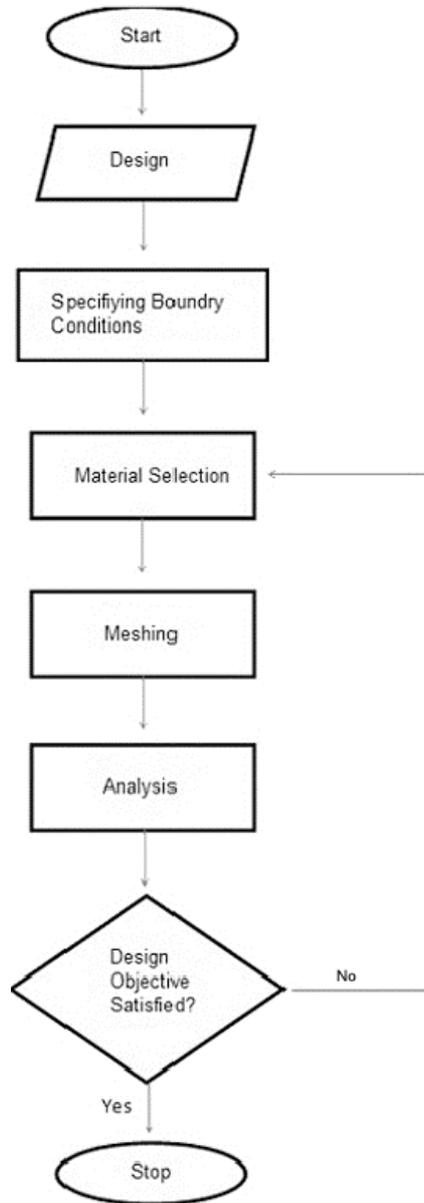
Figure 4.9. Steps of analysis

4.2.1. Distribution of 40 Tonnes of Loading on the Chassis

CAD model of the chassis was transferred to ANSYS Workbench in stp file. This model is shown in figure 4.10. CAD representation of the chassis was cut into small elements. Meshed chassis is illustrated in Figure 4.11. Meshed model has 591861 nodes and 131557 solid elements.More information about the analysis is available in appendix.
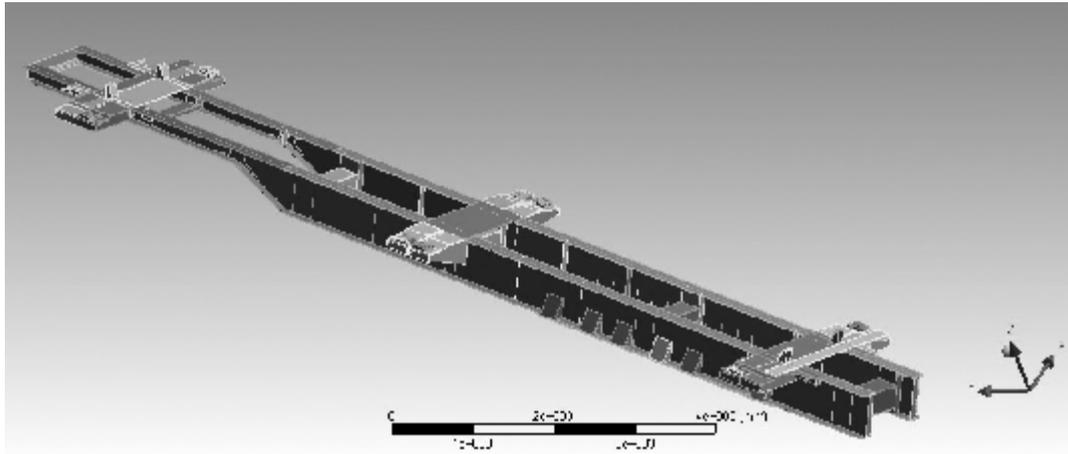
Figure 4.10. 3D model of the chassis in ANSYS Workbench
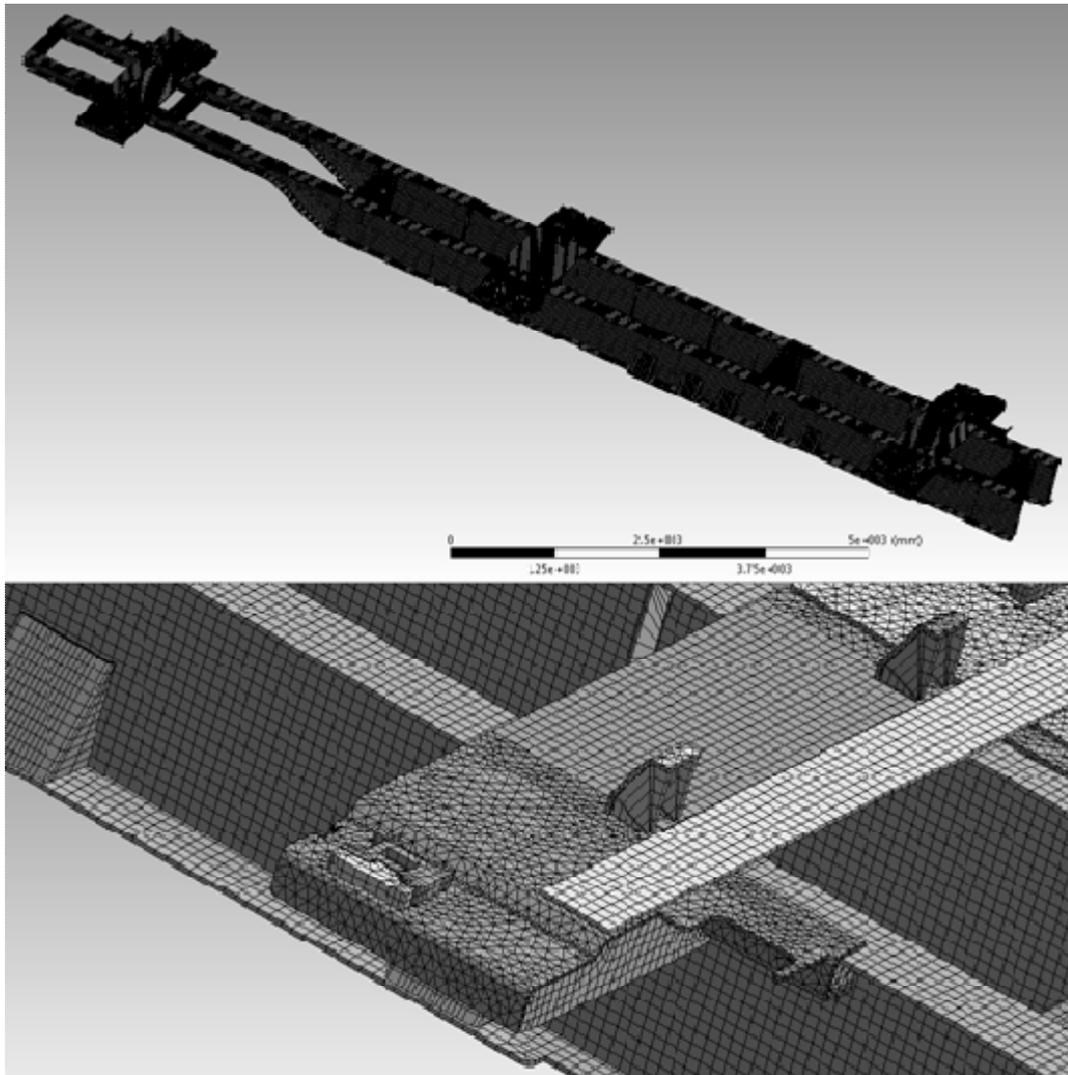
Figure 4.11. Meshed view of the chassis

4 different forces and 2 supported regions were exerted on the chassis (Figure 4.12 and Figure 4.13), these are presented in Table 4.1. 40 tonnes of container weight was applied on the sheets where container settles on the chassis. Also weights of the loader arms were hypothetically applied as 16677N distributed load. Rear axles and king pin regions were restricted in x-y and z directions.

Table 4.1. Boundary conditions of the chassis

Symbol	Type of the Boundary Conditions	Representation	Magnitude
A	Acceleration	Own weight of the chassis due to earth gravity	9806,6 mm/s^2
B	Remote Displacement	Rear axles	-
C	Remote Displacement	King pin	-
D	Remote Force	Weight of the front arm	16677 N
E	Remote Force	Weight of the back arm	16677 N
F	Remote Force	Container weight	392400 N
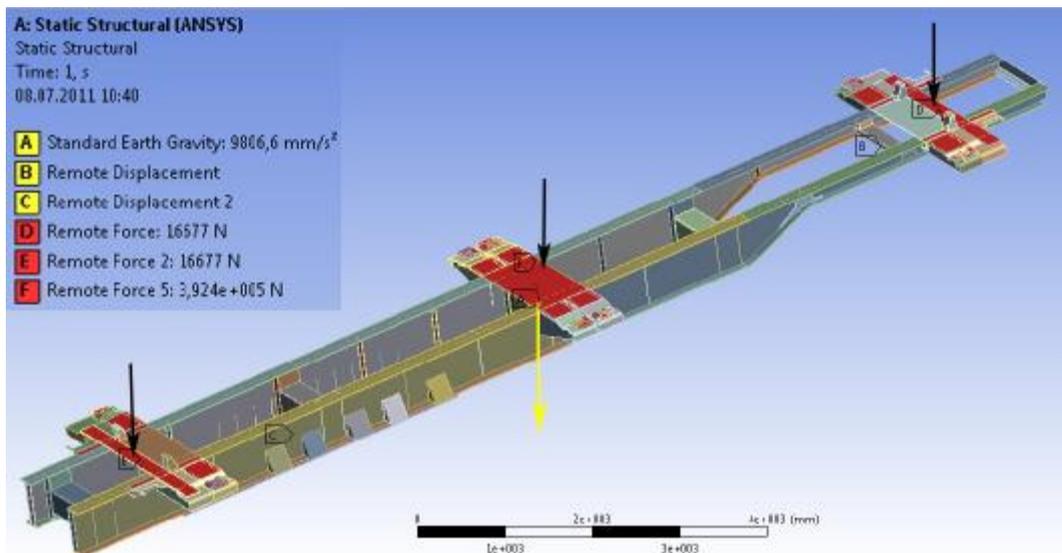
Figure 4.12. Top view of chassis illustrating the details of boundary conditions
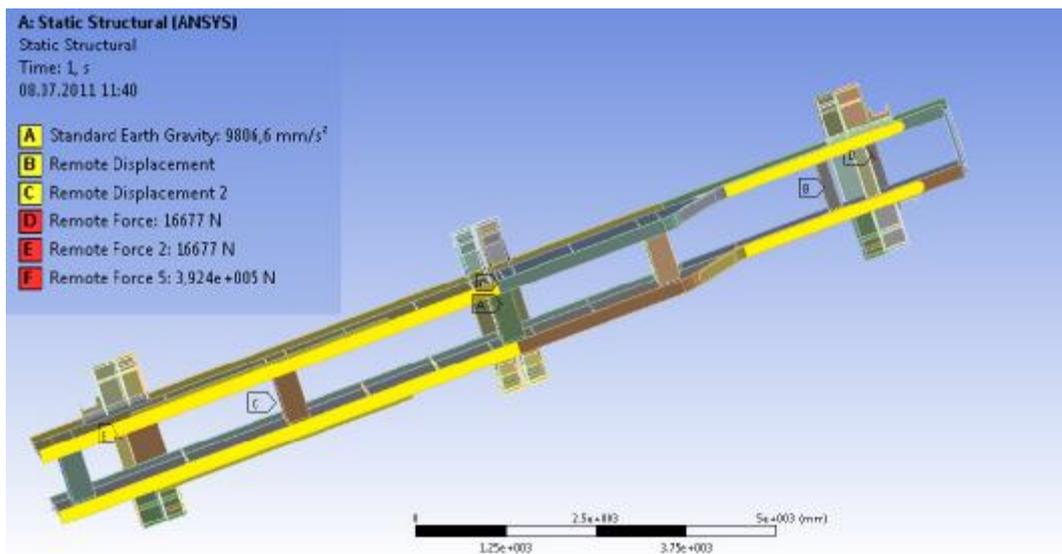
Figure 4.13. Bottom view of chassis illustrating the details of boundary conditions

4.2.2. 40 Tonnes of Loading from the Hooks

CAD model of the sidelifter was transferred to ANSYS Workbench in stp file. This model is shown in Figure 4.14. CAD representation of the sidelifter was cut into small elements. Meshed model has 1159314 nodes and 347437 solid elements (Figure 4.15).More information about the analysis is available in appendix.
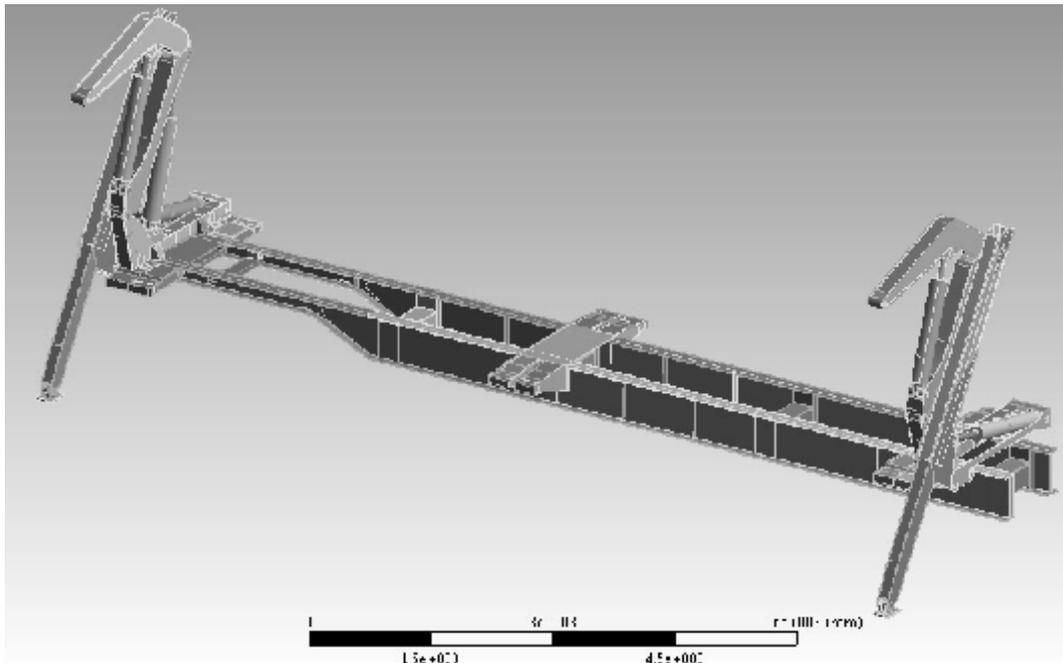
Figure 4.14. 3D model of the chassis in ANSYS Workbench
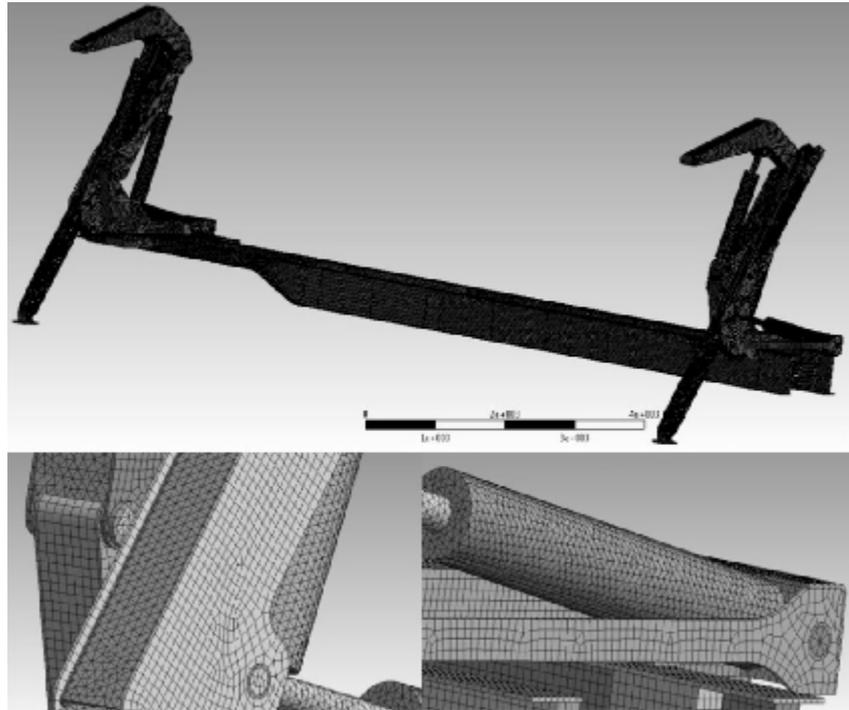
Figure 4.15. Meshed view of the sidelifter

3 different forces and 4 supported regions were exerted on the mechanism (Figure 4.16). 2 Forces were exerted to symbolize 40 tonnes of container weight (exerted as 20 tonnes at 2 different chain connection point) and other force was added to the system to represent own weight of the system. The feet where the legs touch to the ground were accepted as fixed point. Rear axles and king pin regions were restricted in x-y and z directions (Table 4.2).

Totally 6 piston pressures were calculated by hand and applied on the modal (Figure 4.17).

Table 4.2. Boundary conditions of the sidelifter

Symbol	Type of the Boundary Conditions	Representation	Magnitude
A	Acceleration	Own weight of the sidelifter due to earth gravity	$9806,6 \text{ mm/s}^2$
B	Fixed Support	Ground	-
C	Fixed Support	Ground	-
D	Remote Displacement	Rear axles	-
E	Remote Displacement	King pin	-
F	Remote Force	Container weight	196200N
G	Remote Force	Container weight	196200N
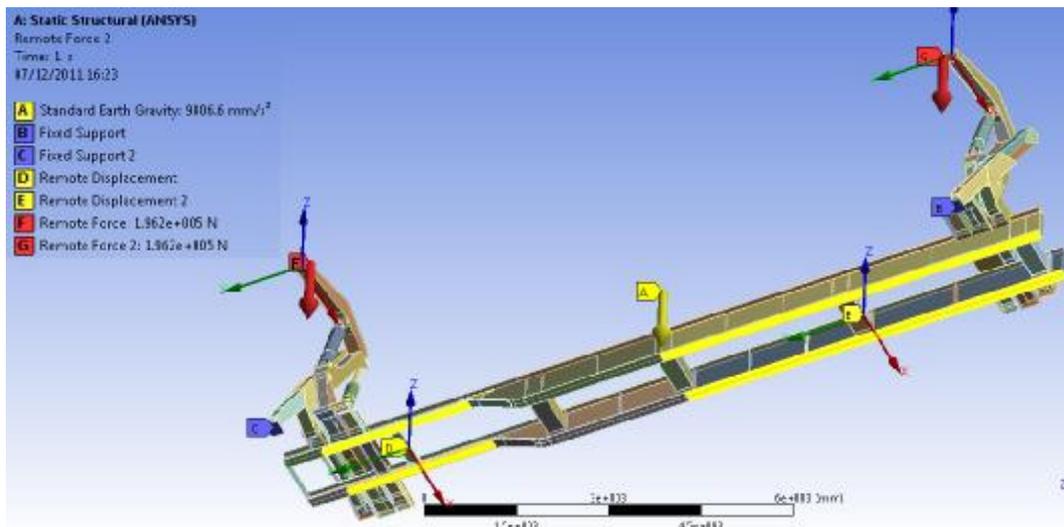
Figure 4.16. Boundary conditions of the sidelifter
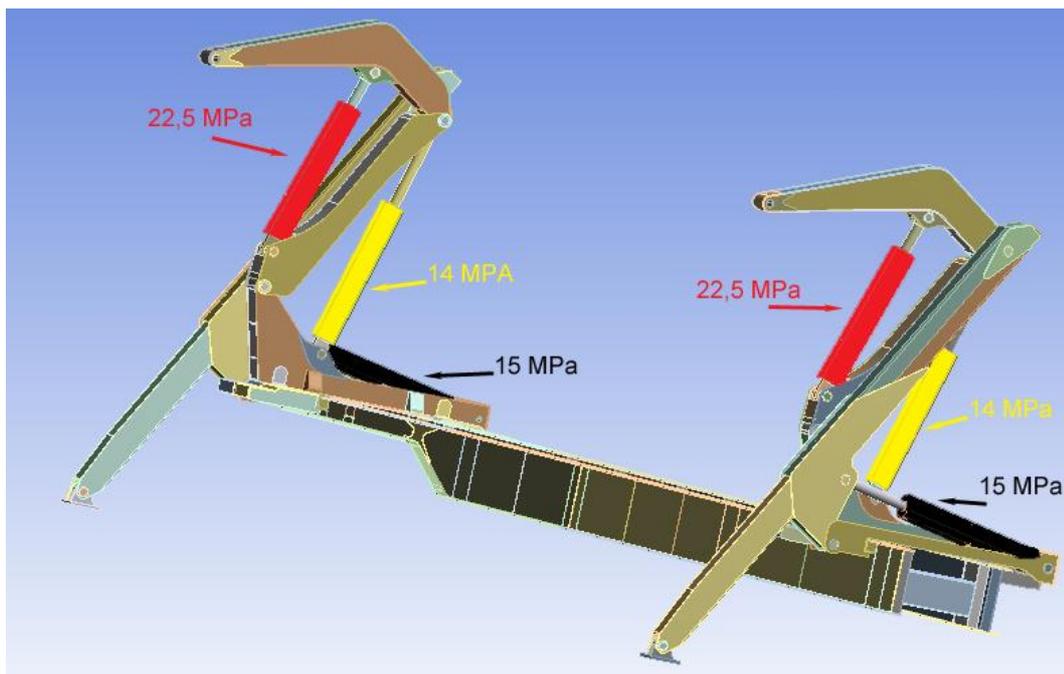
Figure 4.17. Location and values of the hydraulic pistons' pressures

4.3. Manufacturing of the Sidelifter

For manufacture of the prototype, plain sheets are cut with CNC plasma machine, and then these sheets are welded together with gas metal arc process. Formed components are joined and auxiliary equipment are added together to compose the sidelifter. After assembly some make ups were applied such as painting operation. These processes are shown in Figure 4.18.

St 52-3 N steel was used as main material of the sidelifter. Steel grade St 52-3 N is a low carbon, high strength structural steel which can be readily welded to other weldable steel. With its low carbon equivalent, it possesses good cold forming properties. Chemical composition of St 52-3 N quality steel given in Table 4.3 and mechanical properties are given in Table 4.4.

Table 4.3. Chemical composition of St 52-3 N (S355J2G3)

C		Si	Mn	P	S	Nb		Al	N
max	min	max	max	max	max	min	max	min	max
%0,20	%0,15	%0,20	%1,60	%0,035	%0,035	%0,02	%0,04	%0,02	%0,009

Table 4.4. Mechanical properties of St 52-3 N (S355J2G3)

Young's modulus	Poisson's ratio	Tensile yield strength	Tensile ultimate strength
210 GPa	0,3	355 Mpa	520 Mpa

1- Plain sheet before processing

2- Cutting of the sheets with CNC plasma machine

3- Some sheets of the sidelifter after cutting operation

4- Gas metal arc welding
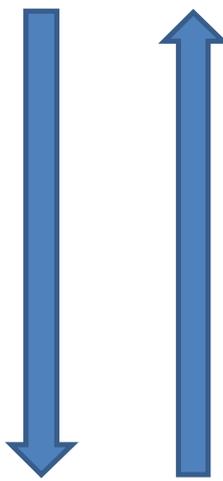
8-Final view

7- Final assembly

6- Auxiliary equipment

5- Components

Figure 4.18. Manufacturing steps of the sidelifter

Figure 4.19. Some sheets of the sidelifter
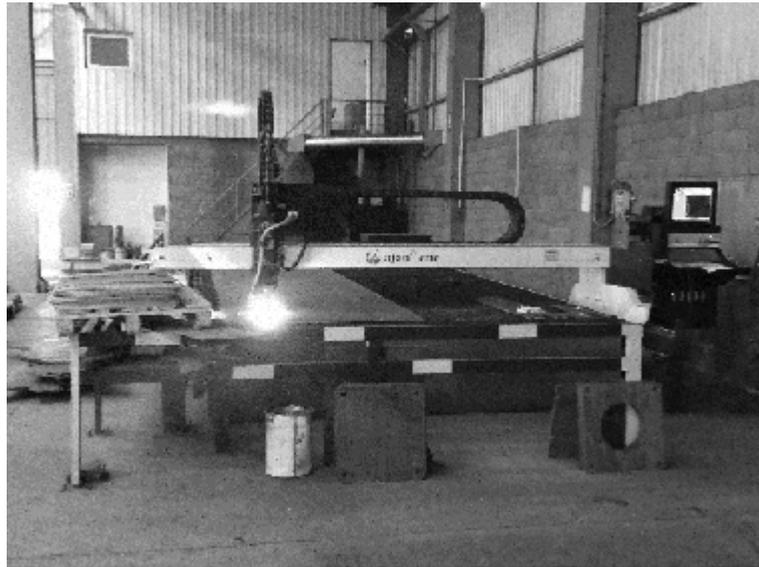
Figure 4.20. CNC plasma machine that is used for cutting sheets

Table 4.5. Properties of CNC plasma machine

Name	CNC Plasma and Oxygen Cutting Machine
Serial number	PP10091 automatic
Production year	2010
Dimensions of the table	3000mm x 12000 mm
Power	4 kW
Input Voltage	AC 380 V/ 3 PH / 50 Hz
Input Current	6 A
Weight	600 kg

4.3.1. Welding of the Sidelifter

Gas metal arc welding was utilized as joining process between sheets. At this process metals were melted and joined by heating them with an arc established between a continuously fed filler wire electrode and the metals, as shown in Figure 4.21. Welding processes are utilized with the machine shown in Figure 4.22 and its properties are presented in Table 4.6.
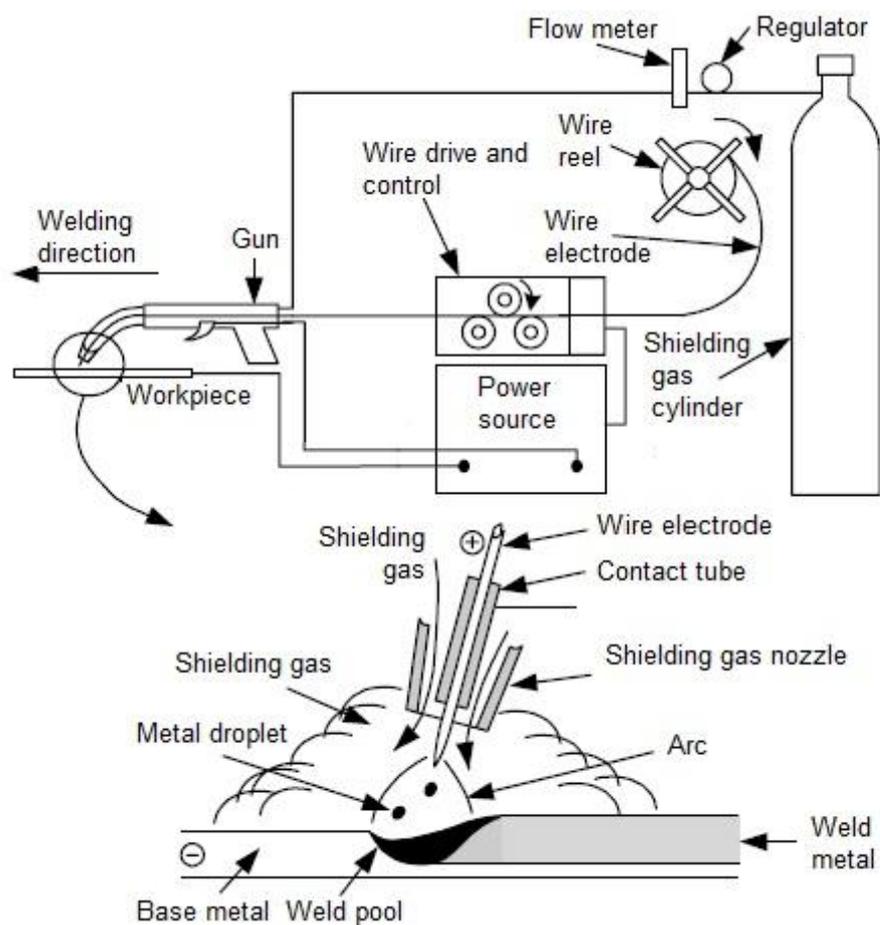
Figure 4.21. Gas–metal arc welding (Kou, 2003)

Figure 4.22. Welding machine that used for welding operations

Table 4.6. Properties of welding machine

Model	GKM 500
Working power	500 Amper
Coolant	Water

During the design steps, some geometry had dimensional tolerances due to some dimensional changes on sheets at welding processes because of thermal expansions. Because of solidification shrinkage and thermal contraction of the weld metal during welding, the workpiece has a tendency to distort such as in Figure 4.23. A view of a welding of the prototype is shown in Figure 4.24.
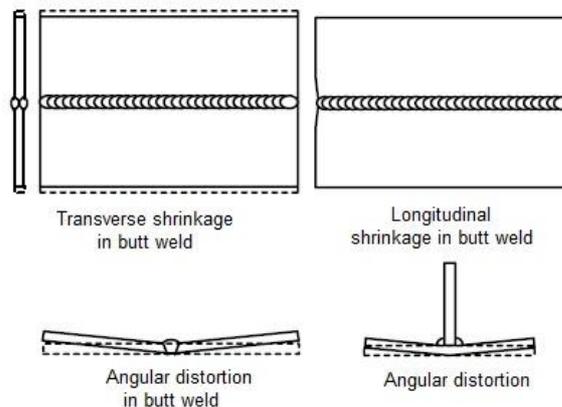
Figure 4.23. Distortions in welded structures

Figure 4.24. View of a weld

4.4. Calculations about the Sidelifter

4.4.1. Strength Calculations of the Semi-Trailer's Chassis

Truck chassis forms the structural backbone of a commercial vehicle. The main function of the truck chassis is to support the components and payload placed upon it. I-profile of the sidelifter chassis was manufactured from St 52-3 N quality steel. Dimensions of I- profile are;
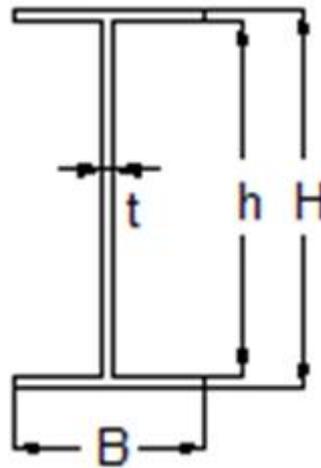
Figure 4.25. View of I-profile

B=200 *mm*,   t= 6 *mm*,   H=580 *mm*,   h=556 *mm*,
b=B-t   b=194 *mm*,

Section modulus (*S*) was calculated as;

$$S = \frac{I}{c} = \frac{BH^3 - bh^3}{6H} \Rightarrow 1631,5 \times 10^3 \ mm^3 \ (5.1.)$$

4.4.1.1. Maximum Moment on the Chassis Due to its Own Weight

If the weight of the chassis is considered as homogenous and the furthest position is chosen for booms placement (Figure 4.26);
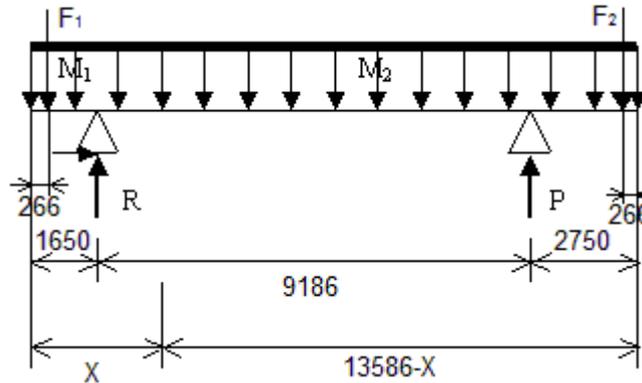
Figure 4.26. Loads that are exerted on the chassis

- Chassis kerb weight = 2880 kgf
- Total booms weight (F1+F2) = $2425 \times 2 \Rightarrow 4850\ kgf$ (5.2.)
- Total kerb weight: G=7730 kgf

$$q = \frac{G}{L} = \frac{2880\ kgf}{13586\ mm} = 0,212\ kgf\ /\ mm\ (5.3.)$$

Moment due to support R;

$$M_o \Rightarrow (13586 \times 0,212) \times (\frac{13586}{2} - 1650) + (2425 \times 11670) - (1384 \times 2425)\ (5.4.)$$
$$- (P \times 9186) = 0$$

P = 4328 kgf

$$P + R = 7730 \Rightarrow R = 7730 - 4328 = 3402\ kgf\ (5.5.)$$

Value and the place of the maximum moment found as;

Maximum moment value is 6825 *kgf.m*

Maximum moment occurs at x = 10836 *mm* (on support P)

4.4.1.2. Maximum Moment on the Chassis Due to 40 Tonnes of Loading

If the weight of the chassis and 40 tonnes load are considered as homogenous and the furthest position is chosen for booms placement (Figure 4.27);
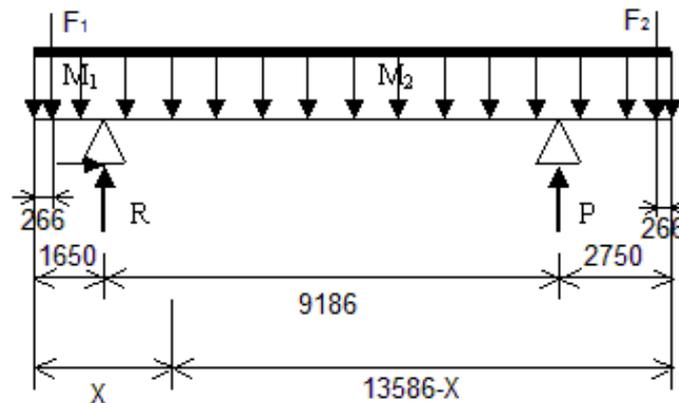
Figure 4.27. Loads that are exerted on the chassis

Weight of the chassis with maximum load:

- Chassis kerb weight + maximum load = 42880 *kgf*

- Total booms weight (F1+F2) = $2425 \times 2 \Rightarrow 4850 \, kgf$ (5.6.)

- Total weight: G=47730 *kgf*

$$q = \frac{G}{L} = \frac{42880}{13586} = 3,156 \, kgf \, / \, mm \quad (5.7.)$$

Moment due to support R;

$$M_o \Rightarrow (13586 \times 3,156) \times (\frac{13586}{2} - 1650) + (2425 \times 11670) - (1384 \times 2425) \quad (5.8.)$$
$$- (P \times 9186) = 0$$

P = 26721 kgf
$P + R = 47730\,kg \Rightarrow R = 47730 - 26721 = 21009\,kgf$ (5.9.)

Value and the place of the maximum moment;

Maximum moment value is 20696 $kgf.m$
Maximum moment occurs at x = 5889 m

4.4.1.3. Stress Values and Factor of Safety about the Sidelifter Chassis

$$G_{1\max} = \frac{M_{1,1\max}}{W} = \frac{6825 \times 10^3 \text{ kg.mm}}{1631,5 \times 10^3 \text{ mm}^3} = 4,183\,kgf/mm^2 \text{ (5.10.)}$$

$$G_{2\max} = \frac{M_{2,1\max}}{W} = \frac{20696 \times 10^3 \text{ kg.mm}}{1631,5 \times 10^3 \text{ mm}^3} = 12,69\,kgf/mm^2 \qquad (5.11.)$$

$$s_{\max} = 12,69\,kgf/mm^2$$

for St 52-3 N material; $s_{all} = 355\,N/mm^2 \Rightarrow 36,2\,kgf/mm^2$ (5.12.)

As $s_{\max} = 12,69\,kgf/mm^2 < s_{all} = 36,2\,kgf/mm^2$; it is safe.

4.4.2. Strength Calculations of the Semitrailer's Axles

Axle is a central shaft for a rotating wheel or gear. On wheeled vehicles, the axle may be fixed to the wheels, rotating with them, or fixed to its surroundings, with the wheels rotating around the axle. Figure 4.28 illustrates axle of the sidelifter and Figure 4.29 shows its dimensions.
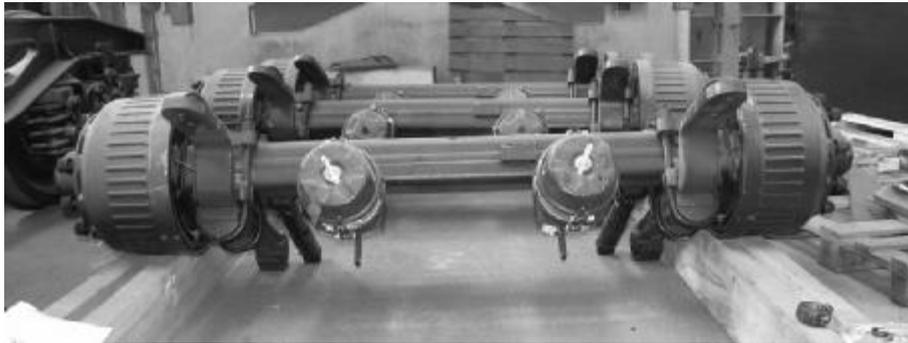
Figure 4.28. Axles of the sidelifter
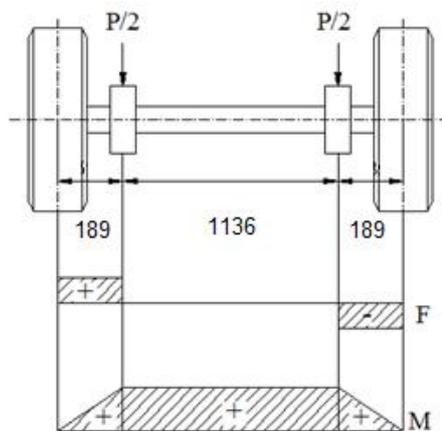
Figure 4.29. Loads that exerted on the axle

Total load on an axle was calculated in equation 5.13;

$$P = \frac{26721\,kgf}{3} = 8907\,kgf \tag{5.13.}$$

$$(5.14.)\quad M_{max} = \frac{P \times L}{2} = \frac{8907\,kgf \times 0,189\,m}{2} \rightarrow 841,7\,kgf.m$$

4.4.3. Brake System Design and Related Calculations

Clutches and brakes are essentially the same device. Each provides a frictional, magnetic, hydraulic, or mechanical connection between two elements. If one element rotates and the other is fixed, it is called a brake. A clutch, thus provide an interruptible connection between two rotating shafts as, for example, the crankshaft of an automobile engine and the input shaft of its transmission. A brake provides an interruptible connection between one rotating element and a nonrotating ground plane as, for example, the wheel of an automobile and its chassis. The same device may be used as either clutch or brake by fixing its output element to a rotatable shaft or by fixing it to ground (Norton, 2003). Representation of a drum break system is illustrated in Figure 4.30.
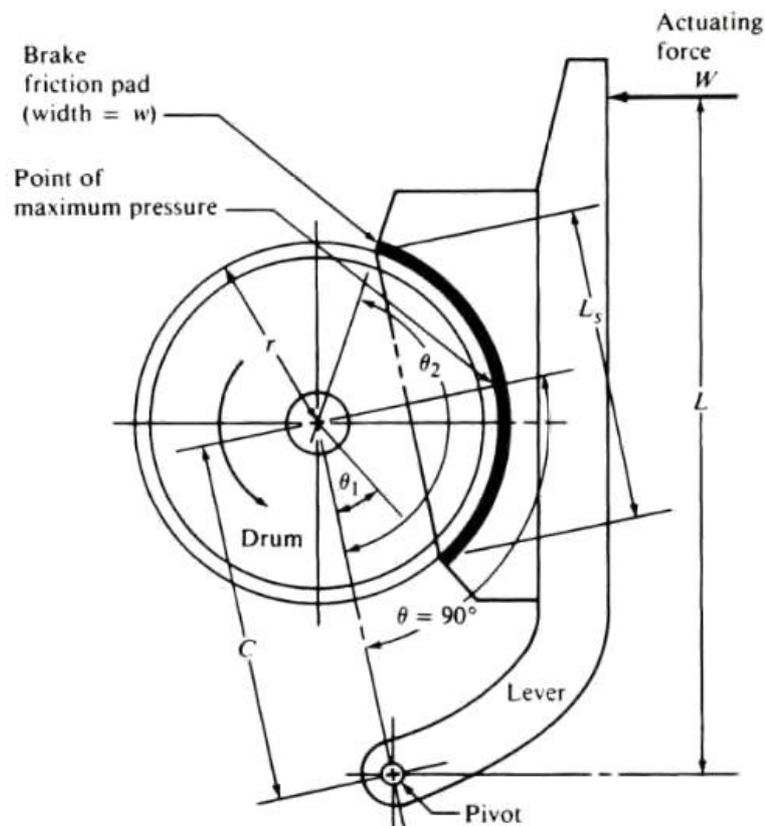
Figure 4.30. Terminology for long shoe drums brake

Width $= 220$ mm,

Radius $= 420$ mm,

$\theta_1 = 30^0$, $\theta_2 = 120^{0.}$

Friction $= 0,25$,

Maximum Pressure (Assumed) $= 1,5Mpa$,

Totally 12 drums on axles

Tire diameter under the load assumed as $0,7m$

$$T_f = r^2 \times f \times w \times p_{max} (\cos q_1 - \cos q_2) \quad (5.15.)$$

Friction torque on drum: $T_f = r^2 \times f \times w \times p_{max} (\cos q_1 - \cos q_2)$ (5.16.)

$$T_f = (420\,mm)^2 \times 0,25 \times 220\,mm \times 1,5\,MPa\,(\cos 30^0 - \cos 120^0) \qquad (5.17.)$$

$T_f = 14553$ Nm

When the vehicle has its gross weight, it should provide at least 4 m/s^2 negative acceleration.

$$a = \frac{F_L}{M} = \frac{14553 \times 12}{0,7 \times 47730} = 5,23\,m/s^2 \qquad (5.18.)$$

as $5,23 m/s^2 > 4m/s^2$, it is safe

4.4.4. Calculations of the Semi-Trailer's Landing Gear Modul Legs

A semi-trailer is normally equipped with landing gear (legs which can be lowered) to support it when it is uncoupled. The sidelifter equipped with JOST Landing Gear Modul legs, which have screw mechanism (Figure 4.31).

Figure 4.31. Label of the landing gear modul legs that used at the sidelifter

If the weight of the chassis and the weight of the container are considered as homogenous and the furthest position is chosen for booms placement (Figure 4.32);
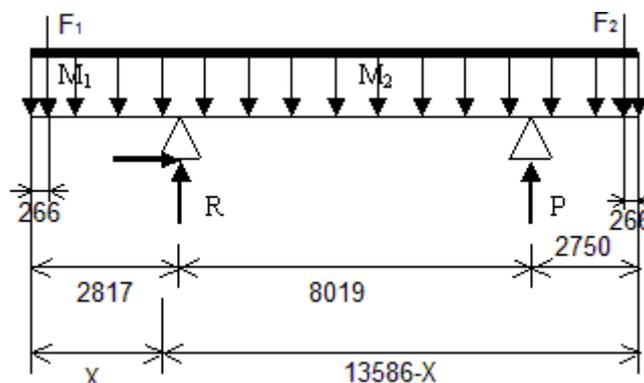

Figure 4.32. Reaction forces of the semitrailer's legs

Moment due to support R;

$$M_o \Rightarrow (13586 \times 3,156) \times (\frac{13586}{2} - 2817) + (2425 \times 10503) - (2425 \times 2551)$$ (5.19.)
$$- (P \times 8019) = 0$$

P $= 23664 \ kgf$

$$P + R = 47730 \, kg \Rightarrow R = 47730 - 23664 = 24066 \, kgf \text{ (5.20.)}$$

According to producer, safe load if 12000 tonnes up to 25000 tonnes

Since the chassis has 2 legs, it has 24000 tonnes up to 50000 tonnes

24000 $kgf \approx$ 24066 kgf, it is safe enough

4.4.5. Calculations of the King Pin

As the tractor reverses under the trailer, a king-pin under the front of the trailer slides into a slot in the skid plate, and the jaws of the fifth wheel close on to it. Dimensions of the king pin are shown in Figure 4.33.
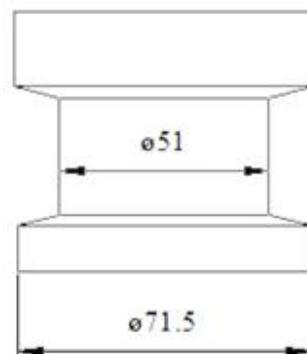
Figure 4.33. Dimensions of king pin (Dimensions in mm)

The material of king pin is C45, which has 53 kg/cm^2 ultimate stress.

Kerb weight of the semi-trailer $= 7730 \ kgf$

Maximum weight of the semi-trailer = 47730 kgf

Section of the king pin,

$$F = \frac{p \times D^2}{4} = \frac{3,14 \times (51)^2}{4} = 2043 \; mm^2 \qquad\qquad (5.21.)$$

The force exerted on the king pin during breaking, P_{max}

Deceleration a = 5,23m/s^2

$$P = \frac{Maximum\,total\,weight \times Deceleration}{Gravity} \qquad\qquad (5.22.)$$

$$P = \frac{47730\,kgf \times 5,23\,m/s^2}{9,81\,m/s^2} = 25446\,kgf \qquad (5.23.)$$

Minimum moment,

$$W = \frac{p \times d^3}{32} = \frac{3,14 \times (71,5)^3}{32} = 35867 \; mm^3 \qquad\qquad (5.24.)$$

Torsion,

$$M_t = M_b = P \times D = 25446 \times 51 = 1298000\,kgf.mm \qquad\qquad (5.25.)$$

Tangential shear stress,

$$t_{max} = \frac{M_t}{W} = \frac{1298000}{35867} = 36,2 \; kgf/mm^2 \qquad\qquad (5.26.)$$

τ_{all} = 53 kg/mm^2

As $t_{max} = 36,2\,kgf/mm^2 < t_{allow} = 53\,kgf/mm^2$, it is safe. $\qquad\qquad$ (5.27.)

4.4.6. Calculations of the Tyres

A tyre is a device that allows objects to be moved easily through rotating on an axle through its center, facilitating movement or transportation while supporting a load, or performing labour in machines. Specifications of wheels on the sidelifter;

Brand of the wheels   = SEMPERIT

Dimensions of the tires = 385x65R 22,5

Load/Speed Index   = 160 K (Load Index= 4500 kg, Speed Index= 110 km/h)

$$L = \frac{P_A}{2} = \frac{8907}{2} = 4453,5 \ kgf \quad \text{The load exert on each tire.} \qquad (5.28.)$$

As 4453,5kgf< 4500 kgf, it is hardly safe.

Figure 4.34. Tyres of the sidelifter

4.4.7. Calculations of the Air Suspension Bellow

P_A= Capacity of axle   = 8907 kgf

Bellow Diameter (D_w)= 315 mm

Bellow's internal pressure (P_i)   = $6,5 \, bar \Rightarrow 0,65 \, MPa$

Bellow influence area $A_w = \dfrac{p \times D_w^2}{4} = 77931 \, mm^2$ (5.29.)

$$F(liftingforce) = P_i \times A_w = 0,65 \times 7793 = 50655N \Rightarrow 5164kgf \quad (5.30.)$$

2 suspension bellow available in each axle;

$$\sum F = 2 \times F = 5164 \times 2 = 10328 \; kgf \qquad (5.31.)$$

$$\sum F = 10328 \; kgf > 8907 \; kgf \text{ , it is safe.} \qquad (5.32.)$$

4.4.8. Hydraulic Cylinders

Totally 10 hydraulic cylinders are used for the movement of the mechanism (Figure 4.35 and Figure 4.36). These hydraulic cylinders were manufactured by Aker Machinery Inc. Sizes were decided at design steps in order to prevent possible intersections with other parts. Decided sizes of cylinders were checked by Aker Machinery Inc., whether enough to handle with 40 tonnes loading. Project of the hydraulic cylinders is shown in Figure 4.37.
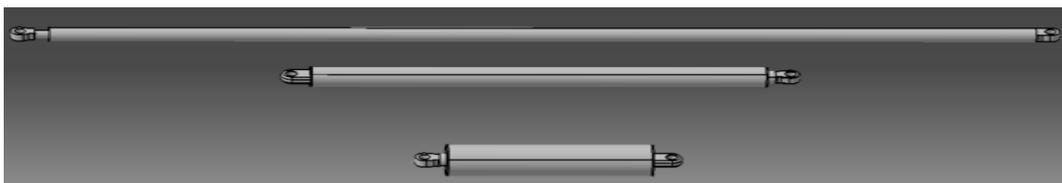
Figure 4.35. CAD model of different sizes of hydraulic cylinders used for the sidelifter

Figure 4.36. Hydraulic cylinders
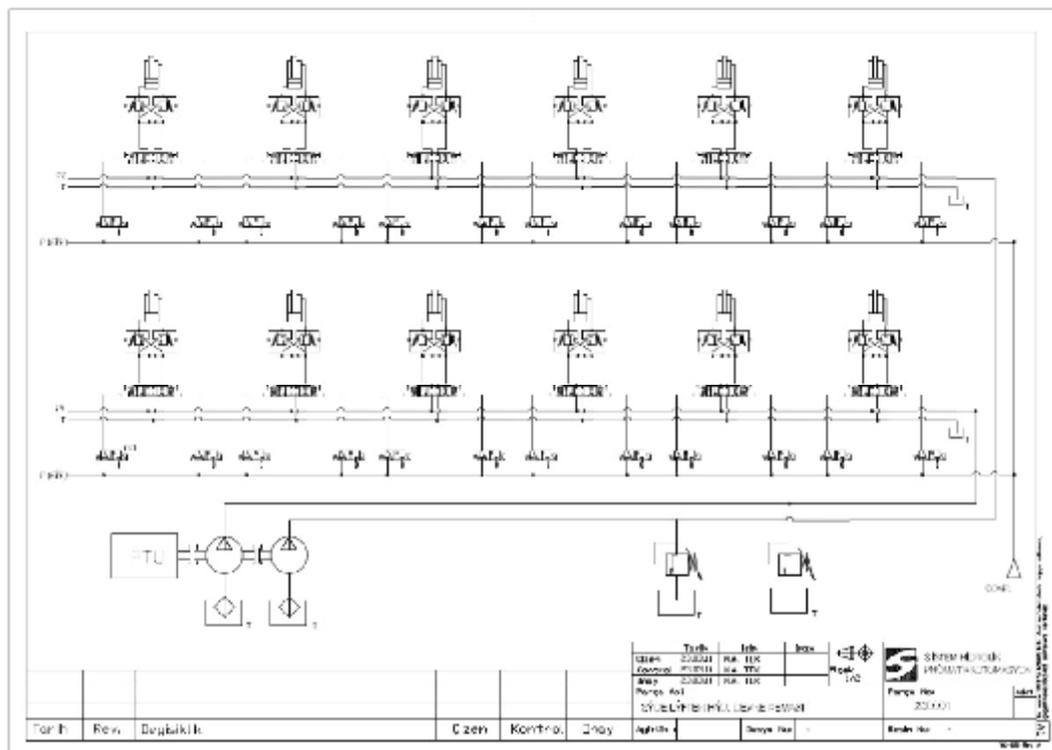
Figure4.37. Project of the hydraulics which are used at the sidelifter

5. RESULTS AND DISCUSSION

5.1. FEM Analyses

5.1.1. Stresses on the Chassis Due to 40 Tonnes of Loading

When 40 tonnes of loading is applied on the chassis, according to data taken from the ANSYS Workbench program, maximum von-Misses stress is found as 367,67 Mpa (Figure 5.13) and normal stresses are found as -353,49 Mpa and 307,32 Mpa (Figure 5.14).More information about the analysis is available in appendix. At maximum stress point, values are suddenly increased because of the structural error. Values and locations of structural errors are given in Figure 5.15. Except that point, von-Misses stress values are less than 355 Mpa which is the maximum yield stress of St 52-3 N quality steel. The second highest stress concentration region value is equal to 314,85Mpa, %88,7 of the yielding point of material in region RV_Kim_SP_14.. It means this sheet satisfies the safety conditions for maximum loading under normal conditions if it is exerted statically. However, the stress level shows that it is high enough to lead to fatigue. The issue of fatigue should be taken into account as a primary failure mechanism except strength requirement.
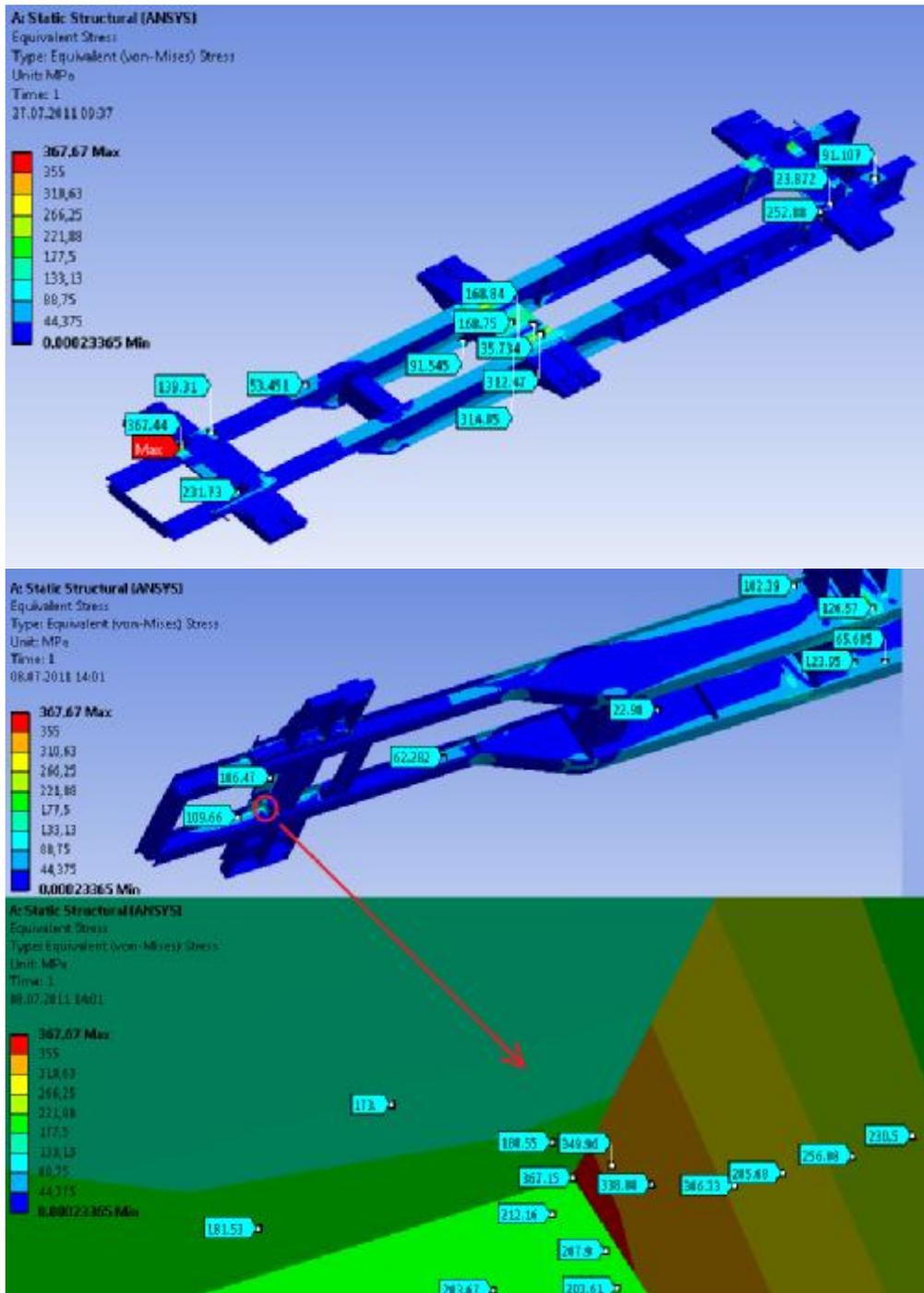
Figure 5.1.von-Mises stresses of the chassis
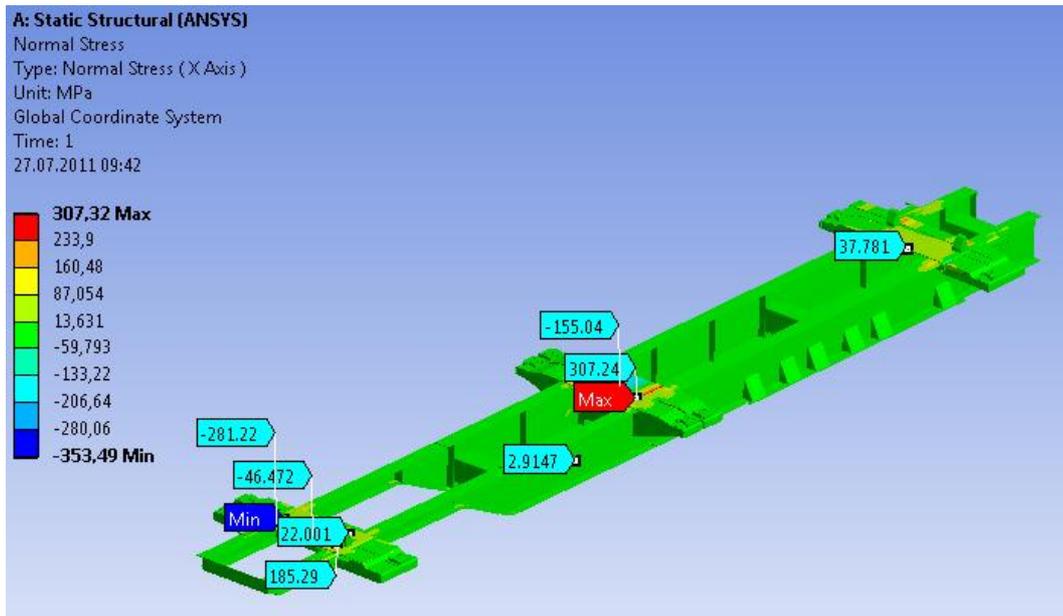
Figure 5.2. Distribution of normal stresses on the chassis under 40 tonnes load
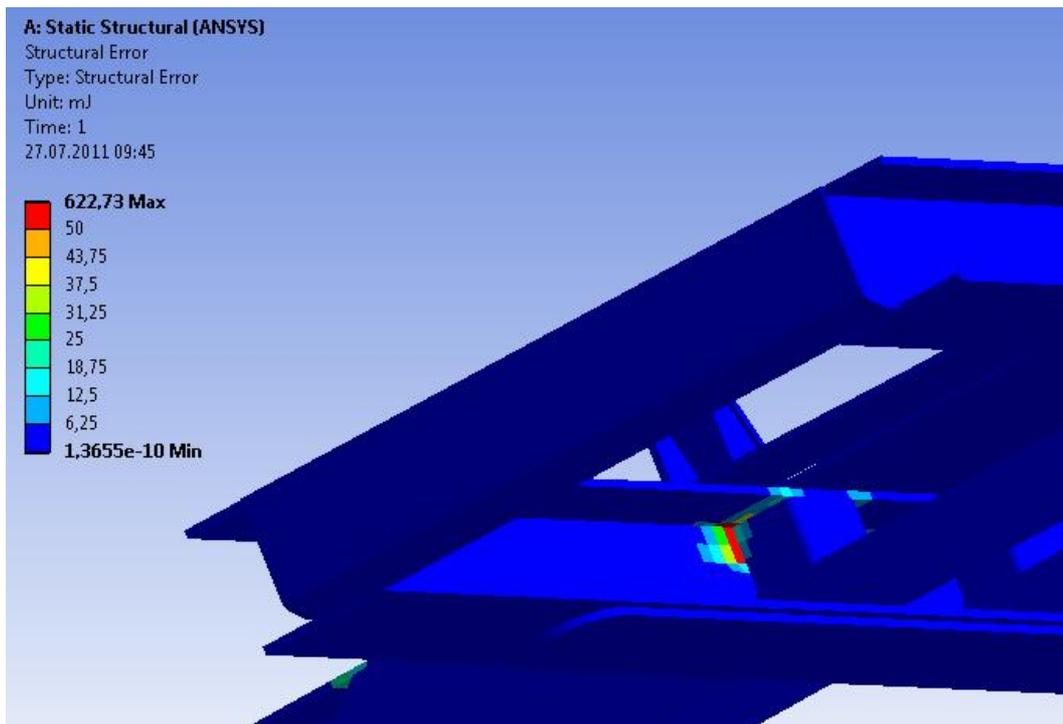
Figure 5.3. Structural errors on the chassis

5.1.2. Stresses Due to 40 Tonnes of Loading from the Hooks

When 40 tonnes of loading is applied from the hooks, according to data taken from the ANSYS Workbench program, maximum von-Mises stress value is found as 1227,8Mpa(More information about the analysis is available in appendix)which is concentrated between the parts RV_KYV_B7 and RV_KYV_SL. In figure 5.16 these regions and stress values are shown and torn of the weld between the parts RV_KYV_B7 and RV_KYV_SL during loading test of 30 tonnes is illustrated in Figure 5.17. 1227,8Mpa value is quite higher than the yield stress (355 Mpa) of St 52-3 N quality steel, which is used for the sidelifter. Therefore, 40 tonnes load, which is symbolizing the maximum weight of a container at two arms, is expected to cause deformation on this region. After construction of the sidelifter this computer model was similarly adapted to real world by using 20 and 30 tonnes instead of 40 tonnes load. After the tests, the mechanism is examined and following problems were observed just as on FEM analyses:

1- The most important problem is the tear of the weld between RV_KYV_B7 sheet and RV_KYV_SL as a result of the deformation of RV_KYV_B7 sheet (Figure 5.16 and figure 5.17). Following modifications are suggested;

- Increasing the thickness of the RV_KYV_B7 sheet
- Strengthen the critical region with new supports
- Choosing the material which has higher elastic modulus than St 52-3 N quality steel has, such as Hardox material
- Redesign of this region is highly recommend

2- Leaning of the arms (Figure 5.18 and figure 5.19)

- Choosing the material which has higher elastic modulus than St 52-3 N quality steel has, such as Hardox material
- Changing the connection location of the hydraulic cylinder
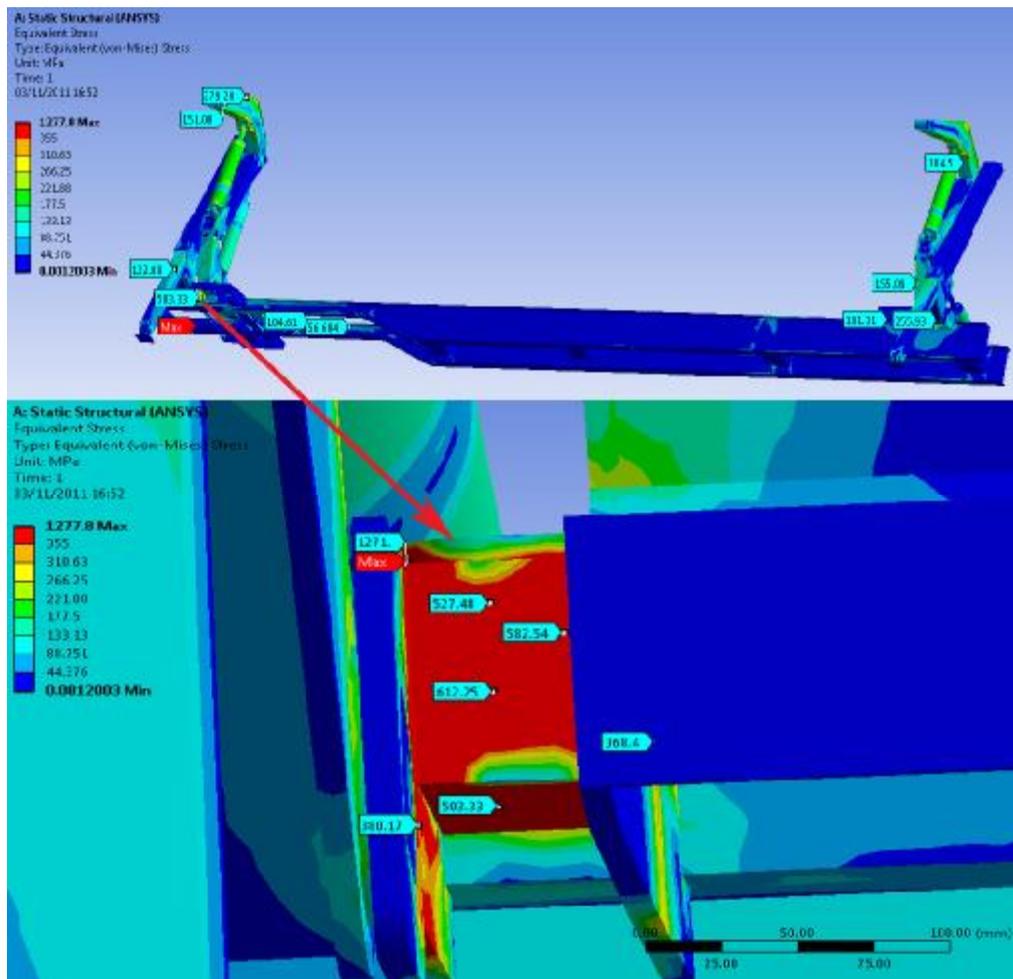
Figure 5.4.von-Mises stresses and critical area under 40 tonnes load

Figure 5.5. The damage as a result of 30 tonnes loading

Figure 5.6. Leaning of the boom under 20 tonnes load
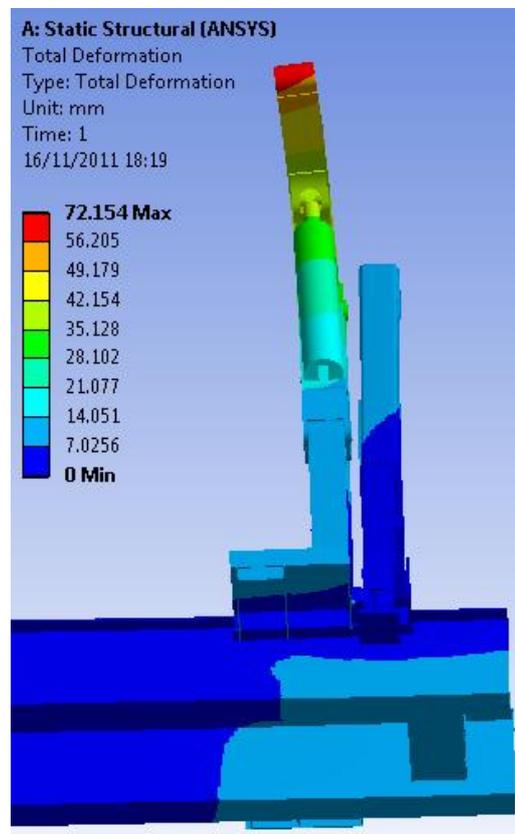
Figure 5.7. Deformation of the boom in FEM analysis under 40 tonnes load

5.2. Cost Analysis

After making all calculations the total cost of the sidelifter was found as 88.719,71 TL. The costs of all components are given separately in Table 5.1.This cost is valid for only prototype product and expected to decrease in case of mass production.

Table 5.1. Cost of the components

Materials	Quantity	Cost
1- Variable Thickness Sheet Materials (6mm–40mm)	For 1 Vehicle	9.610,46 TL
2- Lathe Materials (Transmission, Spindle)	For 1 Vehicle	1.338,40 TL
3- Poliamid	4	566,40 TL
4- Loader Leg	6	30.444,00 TL
5- Main-Leg Piston	2	9.204,00 TL
6- Assistant-Leg Piston	2	1.014,80 TL
7- Open-Close Piston	2	5.428,00 TL
8- Electropneumatic Control Level	2	8.873,60 TL
9- Twin Load-Holding Valves	8	2.171,20 TL
10- Twin Fastener	2	158,12 TL
11- Hydraulic Tandem Pump	1	2.714,00 TL
12- Axles (14 tonnes with air suspension)	3	3.510,89 TL
13- Tires	6	6.301,2 TL
14- SG2 – 1,2 mm Welding Wire	150 kg	362,85 TL
Total	**-**	**88.719,71TL**

5.3. Dimensions and Technical Properties

Basic information about the sidelifter is presented in Table 5.2.

Table 5.2. Some dimensions and properties of the sidelifter

Kerb weight	11.400 kg
Maximum load	40.000 kg
Length	13.586 mm
Width	2.532 mm
Axle width	2.340 mm
Tyres	385x65R 22,5K
Suspension type	Z spring
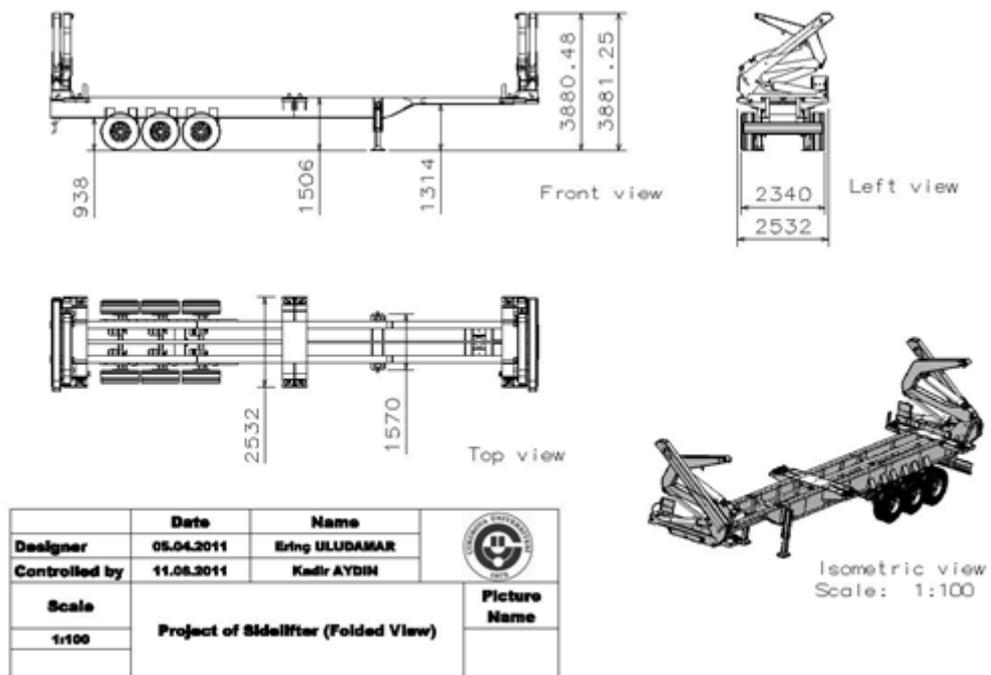
Figure 5.8. Technical drawing of the sidelifter as folded
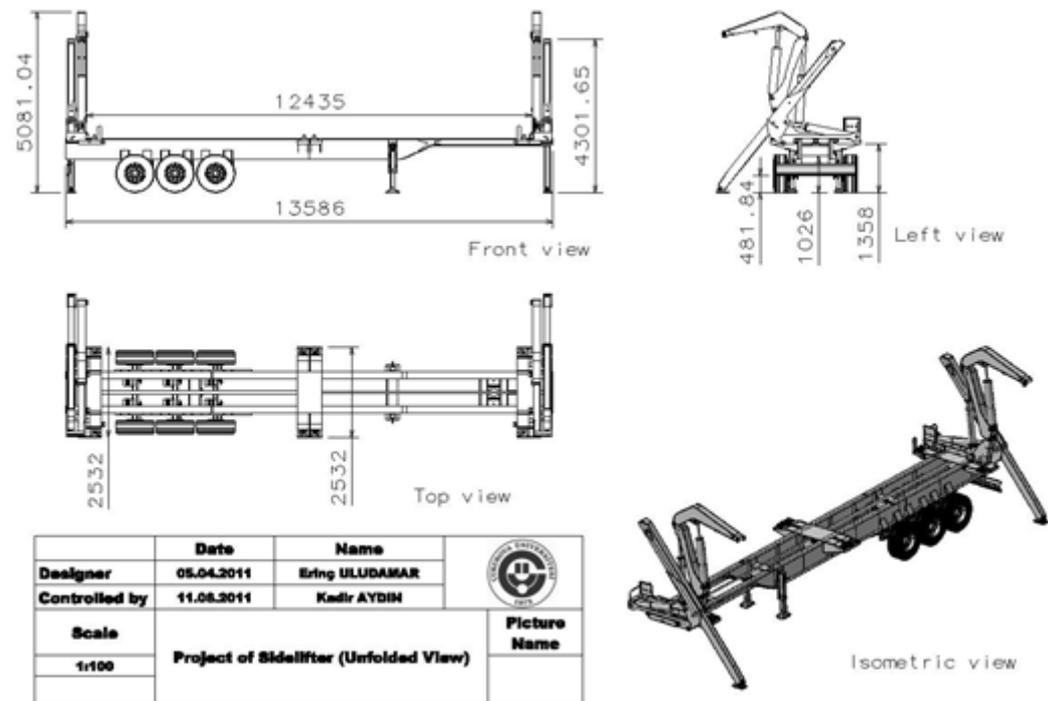
Figure 5.9. Technical drawing of the sidelifter as unfolded

6. CONCLUSION

The aim of this study was designing and developing a low cost and effective mechanism which can easily transfer industrial loads (containers) to railway wagon or trailers of the transporting vehicles. Firstly, previous studies and similar existing mechanisms were examined. Secondly, 3D drawing of the mechanism was prepared and geometric inappropriatenesses were dissipated by several analyses. Then, drafts' were prepared. On practical world, sheets have been cut with CNC plasma machine. These sheets were welded by using Gas–metal arc welding. Lastly, some components such as axles, tires, semitrailers' legs, etc. were added to the mechanism.

St 52-3 N quality steel has been chosen as main material for sidelifter, other kind of materials such as polyamide is used with small amount where slide movement occurs.

The sidelifter, which was developed in Çukurova University Automotive Engineering Laboratories, is able to lift up to 40 tonnes intermodal containers. The prototype was loaded with 20 and 30 tonnes without any fatal damage; however a few problems occurred which were mentioned in chapter 5. Legs and the arms of the mechanism can be moved with the remote control for operator safety. Totally 10 number of hydraulic pistons are used on the mechanism.

In future, different chassis types including telescopic type, whose chassis are shorten and lengthen according to container dimensions, can be developed. Chasses for specific purposes can be also manufactured, which are able to carry one of the following container sizes; 20', 30' and 40'. Arm designs will be modified for better aerodynamics and decrease production costs.

Figure 6.1. Prototype of the sidelifter

REFERENCES

ANONYMOUS, 2007. http://www.steelbro.com/net/faqs/ (Access Date: 14 April 2011)

ANONYMOUS, 2011. http://en.wikipedia.org/wiki/Sidelifter (Access date: 16 April 2011)

ANONYMOUS, 2011. http://www.hafen-hamburg.de/en/content/total-port-container-handling (Access date: 18 April 2011)

ANONYMOUS, 2011a. http://en.wikipedia.org/wiki/CATIA (Access Date: 28 April 2011)

ANONYMOUS, 2011b. http://en.wikipedia.org/wiki/SolidWorks (Access Date: 28 April 2011)

BURDEKIN, M., 2007.Applied metallurgy of steel (B. DAVIDSON and G. W. OWENS edts). Steel Designers' Manual, 6th edition, Blackwell Publishing, pp. 222-247

CANANN, S. A., LIU, Y. C. and MOBLEY, A. V., 1997. Automatic 3D surface meshing to address today's industrial needs. Finite Elements in Analysis and Design, 25: 185-198.

CORRY, P. and KOZAN, E. 2006. An Assignment Model for Dynamic Load Planning of intermodal trains. Computers & Operations Research, 33: 1-17.

FRIES, R., CHOWDHURY, M. and BRUMMOND, J. 2009.Transportation and Security.Transportation Infrastructure Security Utilizing Intelligent Transportation Systems, John Wiley & Sons, INC, Hoboken, USA.pp. 4.

GENG, J., YAN, W., XU, W., TAN, K. B. C., HUANG, H. M., LEE, S. Y., XU, H., HUANG, L. and CHEN, J., 2008. Finite Element Modelling in Implant Dentistry (J. GENG, W. YAN and W. XU, edts), Zhejiang University Press, Hangzhou, pp. 81- 91.

GHIGLIAZZA, R. M., and HOLMES, P., 2002. On the dynamics of cranes, or spherical pendula with moving supports. International Journal of Non-Linear Mechanics, 37: 1211-1221.

IOANNOU, P. A., 2008. Introduction to Intelligent Freight Transportation (P. IOANNOU editor). Intelligent Freight Transportation, CRC Press, Boca Raton, USA, pp. 2 .

KARLINSKI, J., RUSINSKI, E., and SMOLNICKI, T., 2008.Protective Structures for Construction and Mining Machine Operators. Journal of Automation in Construction, 17: 232-244.

KIM, K.H., and GÜNTHER, H.O., 2007. Container terminals and terminal operations (K.H. KIM and H.O. GÜNTHER). Container Terminals and Cargo Systems: Design, Operations Management, and Logistics Control Issues, Springer, Berlin, Germany, pp. 3-12.

KOU, S., 2003.Welding Metallurgy, 2nd edition.USA, 454p.

LIU, G. R. and QUEK, S. S., 2003. Computational Modelling (G. R. LIU and S. S. QUEK, edts). Finite Element Method: A Practical Course, Butterworth-Heinemanni, Oxford, UK, pp. 1-11

MIRALBES, R., and CASTEJON, L., 2009. Design and Optimization of Crane Jibs for Forklift Trucks.Proceedings of the World Congress Analysis, July, 1-3, London, United Kingdom.

MOAVENI, S., 2008.Three-Dimensional Elements (HORTON M. J. and FISCHER L. edts).Finite Element Analysis Theory and Application with ANSYS, 3rd edition, Prentice Hall, USA, pp. 687-753.

MOMME, J. and HVOLBY, H. H., 2002. An Outsourcing Framework: Action Research in the Heavy Industry Sector. European Journal of Purchasing & Supply Management, 8:185–196.

MOTT, R. L., 2004. Materials in Mechanical Design (S. HELBA edts). Machine Elements in Mechanical Engineering, 4th edition, Courier Westford Inc., Westford, pp. 29-82

MURTY, K. G., LIU, J. and LINN, R., 2005. A decision support system for operations in a container terminal. Decision Support Systems, 39:209-332.

NISHIMURA, E., IMAI, A., JANSSENS, G.K., and PAPADIMITRIOU, S., 2009. Container Storage and Transshipment Marine Terminals. Transportation Research Part E, 45: 771-786.

NORTON, R. L., 2006. Machine Design: an integrated approach, 3rd edition , Prentice Hall, USA, pp. 12.

ROKACH, A. J., 1991. Structural Steel Design. McGraw Hill, USA, p. 3.

RUSINSKI, E., CZMOCHOWSKI, J., and MOCZKI, P., 2006. Numerical and Experimental Analysis of a Mine's Loader Boom Crack. Journal of Achievements of Materials and Manufacturing Engineering, 17(2): 273-276.

SASAKI, T. and KAWASHIMA, K., 2008.Remote control of backhoe at construction site with a pneumatic robot system. Automation in Construction, 17: 907-914

SASAKI, T., and KAWASHIMA, K., 2008.Remote control of backhoe at construction site with a pneumatic robot system. Automation in Construction, 17: 907-914.

TRAPPEY, C. V., LIN, G.Y.P., TRAPPEY, A.J.C., LIU, C.S. and LEE, W.T., (in press) Deriving Industrial Logistics Hub Reference Models for Manufacturing Based Economies. Expert Systems with Applications.

UGURLU, U., 2011. http://www.aktueldeniz.com/article_print.php?article_id=84 (Access Date: 02 May 2011)

VIS, I. F. A.and KOSTER, R., 2003. Transshipment of containers at a container terminal: An overview. European Journal of Operational Research, 147:1-16.

WOODBURN, A., ALLEN, J., BROWNE, M., LEONARDI, J., and ESSEN, V. H., 2010. International Road and Rail Freight Transport: The Impact of Globalisation on Activity Levels (N. A. BRAATHEN editor). Globalisation, Transport and the Environment, OECD Publishing. Paris, France, pp.151.

ZAHAVI, E. and BARLAM, D., 2001. Nonlinear Problems in Machine Design. CRC Press LLC, USA, pp. 406.

CURRICULUM VITAE

Erinç ULUDAMAR was born in Adana in 1986. After being graduated Adana Gündoğdu College, he attended to Mechanical Engineering Department of Çukurova University. He graduated from Çukurova University as a Mechanical Engineer in 2009. He started his Master of Science education in Mechanical Engineering Department of Çukurova University in 2009. He has been working as a Research Assistant at the Mechanical Engineering Department of Çukurova University since 2010.

APPENDIX

Geometry

Model (A4) > Geometry

Object Name	Geometry
State	Fully Defined
Definition	
Type	Step
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	5503.5 mm
Length Y	13184 mm
Length Z	3685.3 mm
Properties	
Volume	4.1159e+008 mm³
Mass	3231. kg
Scale Factor Value	1.
Statistics	
Bodies	160
Active Bodies	150
Nodes	591861
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	Yes
CAD Associativity	Yes
Import Coordinate Systems	No
Import Using Instances	Yes
Attach File Via Temp File	Yes
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

Mesh

Model (A4) > Mesh

Object Name	Mesh
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	Off
Relevance Center	Coarse
Element Size	Default
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Minimum Edge Length	0.509130 mm
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	Default (4)
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Please Define
Generate on Refresh	No
Statistics	
Nodes	591861
Elements	131557
Mesh Metric	Element Quality

Model (A4) > Mesh > Mesh Controls

Object Name	Body Sizing
State	Fully Defined
Scope	
Scoping Method	Geometry Selection
Geometry	150 Bodies
Definition	
Suppressed	No
Type	Element Size
Element Size	30. mm
Behavior	Soft

Static Structural (A5)

Model (A4) > Analysis

Object Name	Static Structural (A5)
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C
Generate Input Only	No

Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	Analysis Settings
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled

Moment Convergence	Program Controlled
Displacement Convergence	Program Controlled
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	F:\sidelifteranalizler\orjinalsase4_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	nmm

Model (A4) > Static Structural (A5) > Accelerations

Object Name	Standard Earth Gravity
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Coordinate System 5
X Component	-0. mm/s² (ramped)
Y Component	-0. mm/s² (ramped)
Z Component	-9806.6 mm/s² (ramped)
Suppressed	No
Direction	-Z Direction

Model (A4) > Static Structural (A5) > Loads

Object Name	Remote Displacement	Remote Displacement 2	Remote Force	Remote Force 2	Remote Force 5
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	2 Faces	4 Faces	1 Face		29 Faces
Coordinate System	Coordinate System	Coordinate System 2	Coordinate System 3	Coordinate System 4	Coordinate System 5
X Coordinate	0. mm				
Y Coordinate	0. mm				
Z Coordinate	0. mm				
Location	Defined				
Definition					
Type	Remote Displacement		Remote Force		
X Component	Free	0. mm (ramped)	0. N (ramped)		
Y Component	Free	0. mm (ramped)	0. N (ramped)		
Z Component	0. mm (ramped)		-16677 N (ramped)		-3.924e+005 N (ramped)
Rotation X	Free				
Rotation Y	Free				
Rotation Z	Free				
Suppressed	No				
Behavior	Deformable				
Rotation X		Free			
Rotation Y		Free			
Rotation Z		Free			
Define By			Components		
Advanced					
Pinball Region	All				

Solution (A6)

Model (A4, B4) > Static Structural (A5) > Solution

Object Name	Solution (A6)
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

Model (A4, B4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	Solution Information
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress	Normal Stress	Shear Stress
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				
Definition					
Type	Total Deformation	Equivalent (von-Mises) Elastic Strain	Equivalent (von-Mises) Stress	Normal Stress	Shear Stress
By	Time				
Display Time	Last				
Calculate Time History	Yes				
Identifier					
Use Average		Yes			
Orientation				X Axis	XY Plane
Coordinate System				Global Coordinate System	
Results					
Minimum	7.8951e-003 mm	1.1126e-009 mm/mm	2.3365e-004 MPa	-353.49 MPa	-99.907 MPa
Maximum	15.426 mm	1.7508e-003 mm/mm	367.67 MPa	307.32 MPa	93.781 MPa
Minimum Occurs On	RV_Kim_SP_23	Symmetry of RV_KYV_B7		RV_Kim_SP_3	Symmetry of RV_Kim_SP_14_02
Maximum Occurs On	RV_Kim_SP_24	RV_Kim_SP_17		RV_Kim_SP_24	RV_Kim_SP_1

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	Structural Error
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Structural Error
By	Time
Display Time	Last
Calculate Time History	Yes
Identifier	
Results	
Minimum	1.3655e-010 mJ
Maximum	622.73 mJ
Minimum Occurs On	RV_KYV_B7
Maximum Occurs On	Symmetry of RV_Kim_SP_14_02

Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	Stress Tool
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	Safety Factor
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Use Average	Yes
Identifier	
Results	
Minimum	0.96554
Minimum Occurs On	RV_Kim_SP_17

Structural Steel

Structural Steel > Constants

Density	7.85e-006 kg mm^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Resistivity	1.7e-004 ohm mm

Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
355

Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
355

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
520

Geometry

Model (A4) > Geometry

Object Name	Geometry
State	Fully Defined
Definition	
Type	Step
Length Unit	Meters
Element Control	Program Controlled
Display Style	Part Color
Bounding Box	
Length X	4949.3 mm
Length Y	5566.3 mm
Length Z	13631 mm
Properties	
Volume	8.5691e+008 mm³
Mass	6726.7 kg
Scale Factor Value	1.
Statistics	
Bodies	330
Active Bodies	287
Nodes	1159314
Elements	347437
Preferences	
Import Solid Bodies	Yes
Import Surface Bodies	Yes
Import Line Bodies	No
Parameter Processing	Yes
Personal Parameter Key	DS
CAD Attribute Transfer	No
Named Selection Processing	No
Material Properties Transfer	Yes
CAD Associativity	Yes
Import Coordinate Systems	No
Reader Save Part File	No
Import Using Instances	Yes
Do Smart Update	No
Attach File Via Temp File	Yes
Analysis Type	3-D
Mixed Import Resolution	None
Enclosure and Symmetry Processing	Yes

Mesh

Model (A4) > Mesh

Object Name	Mesh
State	Solved
Defaults	
Physics Preference	Mechanical
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity and Curvature
Relevance Center	Coarse
Initial Size Seed	Active Assembly
Smoothing	Medium
Transition	Fast
Span Angle Center	Coarse
Curvature Normal Angle	60.0 °
Proximity Accuracy	0.5
Num Cells Across Gap	Default (3)
Min Size	25.0 mm
Max Face Size	500.0 mm
Max Tet Size	600.0 mm
Growth Rate	1.40
Minimum Edge Length	2.7865e-003 mm
Inflation	
Use Automatic Tet Inflation	None
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Shape Checking	Standard Mechanical
Element Midside Nodes	Program Controlled
Straight Sided Elements	No
Number of Retries	0
Rigid Body Behavior	Dimensionally Reduced
Mesh Morphing	Disabled
Pinch	
Pinch Tolerance	Default (22.50 mm)
Generate on Refresh	No

Statistics	
Nodes	1159314
Elements	347437
Mesh Metric	Element Quality

Static Structural (A5)

Model (A4) > Analysis

Object Name	Static Structural (A5)
State	Solved
Definition	
Physics Type	Structural
Analysis Type	Static Structural
Solver Target	ANSYS Mechanical
Options	
Environment Temperature	22. °C
Generate Input Only	No

Model (A4) > Static Structural (A5) > Analysis Settings

Object Name	Analysis Settings
State	Fully Defined
Step Controls	
Number Of Steps	1.
Current Step Number	1.
Step End Time	1. s
Auto Time Stepping	Program Controlled
Solver Controls	
Solver Type	Program Controlled
Weak Springs	Program Controlled
Large Deflection	Off
Inertia Relief	Off
Nonlinear Controls	
Force Convergence	Program Controlled
Moment Convergence	Program Controlled
Displacement	Program Controlled

Convergence	
Rotation Convergence	Program Controlled
Line Search	Program Controlled
Output Controls	
Calculate Stress	Yes
Calculate Strain	Yes
Calculate Results At	All Time Points
Analysis Data Management	
Solver Files Directory	F:\sidelifteranalizler\tumu8geomodified8_files\dp0\SYS\MECH\
Future Analysis	None
Scratch Solver Files Directory	
Save ANSYS db	No
Delete Unneeded Files	Yes
Nonlinear Solution	No
Solver Units	Active System
Solver Unit System	nmm

Model (A4) > Static Structural (A5) > Accelerations

Object Name	Standard Earth Gravity
State	Fully Defined
Scope	
Geometry	All Bodies
Definition	
Coordinate System	Coordinate System
X Component	-0. mm/s² (ramped)
Y Component	-0. mm/s² (ramped)
Z Component	-9806.6 mm/s² (ramped)
Suppressed	No
Direction	-Z Direction

Model (A4) > Static Structural (A5) > Loads

Object Name	Fixed Support	Fixed Support 2	Remote Displacement	Remote Displacement 2	Remote Force
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Face		2 Faces		
Coordinate System			Coordinate System	Coordinate System 2	Coordinate System 3
X Coordinate			0. mm		
Y Coordinate			0. mm		-150. mm
Z Coordinate			0. mm		
Location			Defined		
Definition					
Type	Fixed Support		Remote Displacement		Remote Force
Suppressed	No				
X Component			0. mm (ramped)		0. N (ramped)
Y Component			0. mm (ramped)		0. N (ramped)
Z Component			0. mm (ramped)		-1.962e+005 N (ramped)
Rotation X			Free		
Rotation Y			Free		
Rotation Z			Free		
Behavior			Deformable		
Rotation X				Free	
Rotation Y				Free	
Rotation Z				Free	
Define By					Components
Advanced					
Pinball Region			All		

Model (A4) > Static Structural (A5) > Loads

Object Name	Remote Force 2	Pressure	Pressure 2	Pressure 3	Pressure 4
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	2 Faces	1 Face			
Coordinate System	Coordinate System 4				
X Coordinate	0. mm				
Y Coordinate	150. mm				
Z Coordinate	0. mm				
Location	Defined				
Definition					
Type	Remote Force	Pressure			
Define By	Components	Normal To			
X Component	0. N (ramped)				
Y Component	0. N (ramped)				
Z Component	-1.962e+005 N (ramped)				
Suppressed	No				
Behavior	Deformable				
Magnitude		22.5 MPa (ramped)	-14. MPa (ramped)	15. MPa (ramped)	22.5 MPa (ramped)
Advanced					
Pinball Region	All				

Model (A4) > Static Structural (A5) > Loads

Object Name	Pressure 5	Pressure 6	Pressure 7	Pressure 8	Pressure 9
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	1 Face		3 Faces	1 Face	2 Faces
Definition					
Type	Pressure				
Define By	Normal To				
Magnitude	-14. MPa (ramped)	15. MPa (ramped)	22.5 MPa (ramped)	-14. MPa (ramped)	14. MPa (ramped)
Suppressed	No				

Model (A4) > Static Structural (A5) > Loads

Object Name	Pressure 10	Pressure 11	Pressure 12	Pressure 13	Pressure 14
State	Fully Defined				
Scope					
Scoping Method	Geometry Selection				
Geometry	3 Faces		1 Face	2 Faces	3 Faces
Definition					
Type	Pressure				
Define By	Normal To				
Magnitude	15. MPa (ramped)	22.5 MPa (ramped)	-14. MPa (ramped)	14. MPa (ramped)	15. MPa (ramped)
Suppressed	No				

Solution (A6)

Model (A4) > Static Structural (A5) > Solution

Object Name	Solution (A6)
State	Solved
Adaptive Mesh Refinement	
Max Refinement Loops	1.
Refinement Depth	2.

Model (A4) > Static Structural (A5) > Solution (A6) > Solution Information

Object Name	Solution Information
State	Solved
Solution Information	
Solution Output	Solver Output
Newton-Raphson Residuals	0
Update Interval	2.5 s
Display Points	All

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	Total Deformation	Equivalent Elastic Strain	Equivalent Stress	Normal Stress	Shear Stress
State	Solved				
Scope					
Scoping Method	Geometry Selection				
Geometry	All Bodies				

Definition					
Type	Total Deformation	Equivalent (von-Mises) Elastic Strain	Equivalent (von-Mises) Stress	Normal Stress	Shear Stress
By	Time				
Display Time	Last				
Calculate Time History	Yes				
Identifier					
Use Average		Yes			
Orientation				X Axis	XY Plane
Coordinate System				Global Coordinate System	
Results					
Minimum	0. mm	5.7155e-009 mm/mm	1.2003e-003 MPa	-784.12 MPa	-474.12 MPa
Maximum	72.154 mm	6.0848e-003 mm/mm	1277.8 MPa	864.71 MPa	510.97 MPa
Minimum Occurs On	RV_KYV_P9_1	RV_KYV_B7		ek1	
Maximum Occurs On	RV_KYV_D2	ek1		RV_KYV_H1	ek1

Model (A4) > Static Structural (A5) > Solution (A6) > Results

Object Name	Structural Error
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Structural Error
By	Time
Display Time	Last
Calculate Time History	Yes

Identifier	
Results	
Minimum	2.6882e-009 mJ
Maximum	1205.5 mJ
Minimum Occurs On	RV_KYV_B7
Maximum Occurs On	ek1

Model (A4) > Static Structural (A5) > Solution (A6) > Stress Safety Tools

Object Name	Stress Tool
State	Solved
Definition	
Theory	Max Equivalent Stress
Stress Limit Type	Tensile Yield Per Material

Model (A4) > Static Structural (A5) > Solution (A6) > Stress Tool > Results

Object Name	Safety Factor
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Safety Factor
By	Time
Display Time	Last
Calculate Time History	Yes
Use Average	Yes
Identifier	
Results	
Minimum	0.27782
Minimum Occurs On	ek1

Structural Steel

Structural Steel > Constants

Density	7.85e-006 kg mm^-3
Coefficient of Thermal Expansion	1.2e-005 C^-1
Specific Heat	4.34e+005 mJ kg^-1 C^-1
Thermal Conductivity	6.05e-002 W mm^-1 C^-1
Resistivity	1.7e-004 ohm mm

Structural Steel > Compressive Yield Strength

Compressive Yield Strength MPa
355

Structural Steel > Tensile Yield Strength

Tensile Yield Strength MPa
355

Structural Steel > Tensile Ultimate Strength

Tensile Ultimate Strength MPa
520