ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF MECHANICAL AND INDUSTRIAL ENGINEERING

DYNAMIC SIMULATION of SLOSHING EFFECT on FLUID TRANSPORTING FREIGHT-WAGON

MSc. Thesis

by

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Advisor

Daniel Tilahun (Dr.)

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(Railways Engineering Program)

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ABSTRACT

The discussion and definition of the MBS (Multi Body Simulation) parameters and the methods and the types of the MBS softwares along with their special features and advantages has been stated in the start of this thesis so as to get cleared on what is going to be done in MBS title.

Different related previously published and reference written articles of literatures regarding the idea of fluid dynamic simulation have then been described to focus on the expected results of this thesis. Also, the limitation and the focusing area have been fortunately guided by these literatures.

The load shift and roll performance characteristics of the vehicle with the optimal cross-sections are compared with those of the currently used various other types of tank cross-sections (for various liquid fill conditions); here, the manufacturing cost comparison of local against the imported tankers also duly analyzed referring the cost-break down approach in local factories. The results have been compared and the conclusions with advantages are discussed to decide in selection of the optimal tank cross sectional geometry for shape modeling.

The modeling of the tank structure along with the simplified bogie supporting the fluid wagons is done by using the Solidworks 2014 software to show the shape and the relative part mates' contacts to perform the allowable relative motion analysis with respect to the mate.

The behavior of the fluid wagon containing the viscous fluids of preferably petroleum base natural oil during the vehicle running has been simulated using both Simpack and ANSYS fluent CFD workbench packages after performing the modeling and the meshing analysis.

The graphic result reports from Analytic and each of the MBS softwares have been compiled and discussed so as to observe in comparing the load, the stress and the motion results to decide the critical motion parameters.

Key Words: Sloshing, Freight transport, Baffle, Tank Wagon, Multi-Body Simulation MBS, cost break-down, inviscid …

Contents

TERMS, NOTATIONS and ABBREVIATIONS

Terms	**Definition**
Baffle	A non-liquid tight transverse or longitudinal partition in a tank
Sloshing	A swinging unstable motion behavior of liquids inside a container
Tank	A container that has a liquid-full capacity that is used for transporting petroleum based flammable liquids and that is mounted permanently or temporarily on a vehicle
Compartment	A liquid-tight division of a tank
Tank Wagon	A vehicle or trailer specially constructed for the bulk transport of petroleum liquids or gases by road or rail, with a tank fixed to the chassis.
Freight wagons	unpowered railway vehicles that are used for the transportation of cargo (containers are used in most long-haul cargo transport)
Crude Oil	A mixture of hydrocarbons that exists in liquid phase in natural underground reservoirs and remains liquid at atmospheric pressure after passing through surface separating facilities.
Jet Fuel	A refined petroleum product used in jet aircraft engines. It includes kerosene- type jet fuel and naphtha-type jet fuel
Lucrative	well-paid, profitable, beneficiary
placarded	Advertised for promotion purpose
In-viscid	Sticky, bulky and attached
Granules	Micronized solids, particles

Notation	**Description**
$\overrightarrow{r_c}$	Position vector of cell ‘c’ from origin ‘o’.
$\overrightarrow{F}$	Force vector
$\overrightarrow{M}$	Moment vector
F_x,F_y, and F_z	resultant slosh forces acting on the tank wall along the fixed x, y and z axes
$\vec{\imath}$, $\vec{\jmath}$, and $\overrightarrow{k}$	Unit vectors acting along the fixed x, y and z axes
$\overrightarrow{A_c}$	Area vector
$\overrightarrow{P_c}$	pressure Vector of cell ‘c’
V	Fluid volume pet unit length of the tank at steady-state condition.
$V0$	Fluid volume pet unit length of the tank at static condition.

$\sum_{c}^{wetarea}$	Summation of parameters in the boundaries limited between cell ‘c’ and wet-area
ρ	Density
f_i^w, f_i^g and f_i^r	The basic, the gradient, and the curving resistance forces acting on wagon *i* resulting from the slope of the track.
f_i^c	the force of the rear coupler on wagon ‘i’
m_i	mass of fluid ‘i’
$\ddot{s}_i$	Second derivative of arc length coordinate to represent acceleration of wagon ‘i’
R_i	Residual equation at an element vertex i
dV^e	the volume of the element
ε	Difference in static and steady-state volume per unit length of tank.
ax, ay, az	Longitudinal(x), lateral (y) and vertical (z) component of vehicle acceleration
Q	the conservation equation expressed on an element basis
θ	Sprung mass roll angle.
ø	Free surface inclination to the horizontal
R	Radius of circular cross-section
К - e	Turbulence dissipation
К	Turbulence Kinetic energy
e	Turbulence Dissipation Rate

Abbreviations	**Definition**
MBS	Multi-body Simulation
CAE	Computer Aided Engineering
CFD	Computational Fluid Dynamics
UIC	International Union of Railways Corporation (the primary members are Russia, France, Spain
EPE	Ethiopian Petroleum Enterprise
CDE	*La Compagnie Du chemin de fer djibouto-éthiopien* (Ethio-Djibouti RW)
ICA	International Communication Association
P.D.E	Partial Differential Equation
Mfg.	Manufacturing
TDMA	The Tri-Diagonal Matrix *Algorithm*
NR	National Rail

SW	Solid-Works
OH	Over Head
VOF	Volume of fluid
US	United States
FVM	Finite Volume Method
cg	Center of Gravity
FOB	Free on Board - A trade term requiring the seller to deliver goods
PASIMODO	PArticle SImulation and MOlecular Dynamics in an Object oriented fashion
KCMPF	Kaliti Construction Materials Production Factory

LIST of FIGURES and TABLES

CHAPTER ONE

INTRODUCTION

1.1. Background

Transport of freight using fixed rails has a very long history. There are examples of vehicles being pushed or pulled along rails by humans and animals for at least two thousand years. Then during the 18th century, the industrial revolution began to generate unprecedented demand for high capacity movement of raw materials, especially of coal. The inflexibility of canals and the very poor state of roads led to experimentation and rapid technological progress with a wide range of rail materials (stone, timber, cast iron, wrought iron) and of locomotion (people, animals, gravity, racks, steam).

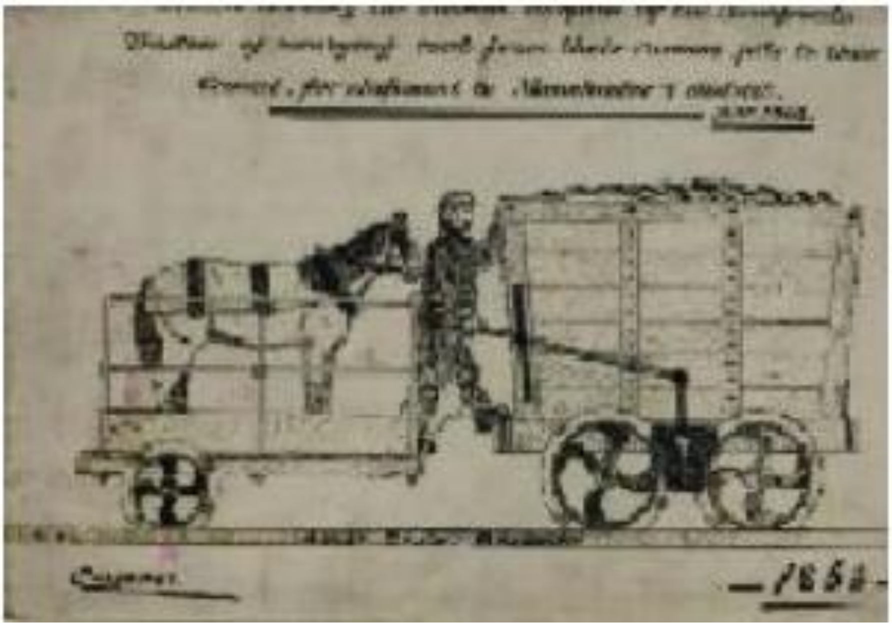


Fig. 1-1. Intermodal and multi modal freight [1]

The result was the emergence of a convention of coupled freight wagons equipped with flanged steel wheels on steel rails, and pulled by a powered locomotive. This configuration still characterizes freight railways today. Most rail freight has always been part of a longer supply chain. Early railway routes in England connected coal mines to canals for on-transport to factories (see Figure 1-1 where gravity on one way and horse power the other is used for this 18th century built railway in the UK).

By the end of the nineteenth century the more industrialized countries, particularly in North America, Europe, European Russia and Japan and some other countries such as India and Argentina, had identifiable and generally (at least within countries) interoperable national railway networks, though ownership was often divided between many railway companies. These national networks provided rail connection between industrial and population centers and major ports. Except where there were parallel commercial waterways they more or less monopolized long-distance overland freight transport. But in other parts of the world, particularly in Africa and Asia (but also for example, in Australia), railways often consisted of isolated lines or small networks, feeding into ports, but lacking wider regional connectivity. China has undertaken a massive program of network development to overcome such a deficiency of freight transport [1].

Railways are among the safest means of transportation to displace bulk volume of freights over a wide range of distances like a vehicle or trailer specially constructed for the bulk transport of petroleum liquids or gases by road or rail, with a tank fixed to the chassis. However, safety standards are continuously reviewed and updated in an effort to further reduce the occurrence of accidents. Maneuvering of the freight train in both the acceleration and the braking cases set the liquid cargo into motion. This longitudinal sloshing motion of the fluid cargo inside the tanks initiated a swinging motion of some components of the coupling of the draft gear. The coupling gear consists of traction hooks and coupling screws that are located between buffers designed as per UIC (Union of International railway Committee) standard. One of the coupling screws is placed in the traction hook of the opposite wagon thus joining the two wagons, whereas the un- used coupling screw rests on a hanger. Such a swinging effect leads the total vehicle to be unstable [2]

Fig. 1-2. Long Vehicle freight Transporting [2]

Rail freight transport is the use of railroads to transport cargo as opposed to human passengers. A **freight train** or **goods train** is a group of freight cars (US) or goods wagons (UIC) hauled by one or more locomotives on a railway, transporting cargo all or some of the way between the shipper and the intended destination as part of the logistics chain. Trains may haul bulk material, intermodal containers, general freight or specialized freight in purpose-designed cars. Rail freight practices and economics vary by country and region. When considered in terms of ton-miles or ton-kilometers hauled per unit of energy consumed, rail transport can be more efficient than other means of transportation. Maximum economies are typically realized with bulk commodities. Traditionally, large shippers build factories and warehouses near rail lines and have a section of track on their property called a *siding* where goods are loaded on to or unloaded from rail cars. Rail freight uses many types of goods wagon (UIC) or freight car (US). These include box cars (US) or covered wagons (UIC) for general merchandise, flat cars (US) or flat wagons (UIC) for heavy or bulky loads, well wagons or “low loader” wagons for transporting road vehicles; there are refrigerator vans for transporting food, simple types of open-topped wagons for transporting bulk material, such as minerals and coal, and tankers for transporting liquids and gases. Most coal and aggregates are moved in hopper wagons or gondolas (US) or open wagons (UIC) that can be filled and discharged rapidly, to enable efficient handling of the materials. A major disadvantage of rail freight is its lack of flexibility. In part for this reason, rail has lost much of the freight business to road transport. Many governments are now trying to encourage more freight onto trains, because of the environmental benefits that it would bring; rail transport is very energy efficient. In Europe (particularly Britain) many manufacturing towns developed before the railway. Many factories did not have direct rail access. This meant that freight had to be shipped through a goods station, sent by train and unloaded at another goods station for onward delivery to another factory. When Lorries (trucks) replaced horses it was often economic and faster to make one movement by road. In the United States, particularly in the West and Mid-West towns developed with railway and factories often had direct rail connection. Despite the closure of many minor lines carload shipping from one company to another by rail remains common. Freight railroads relationship with other modes of transportation varies widely. There is almost no interaction with airfreight, close cooperation with ocean-going freight and a mostly competitive relationship with long distance trucking and barge transport. Many businesses ship their products by rail if they are shipping long distance because it can be cheaper to ship in large quantities by rail than by truck; however barge shipping remains a viable competitor where water transport is available. [1]

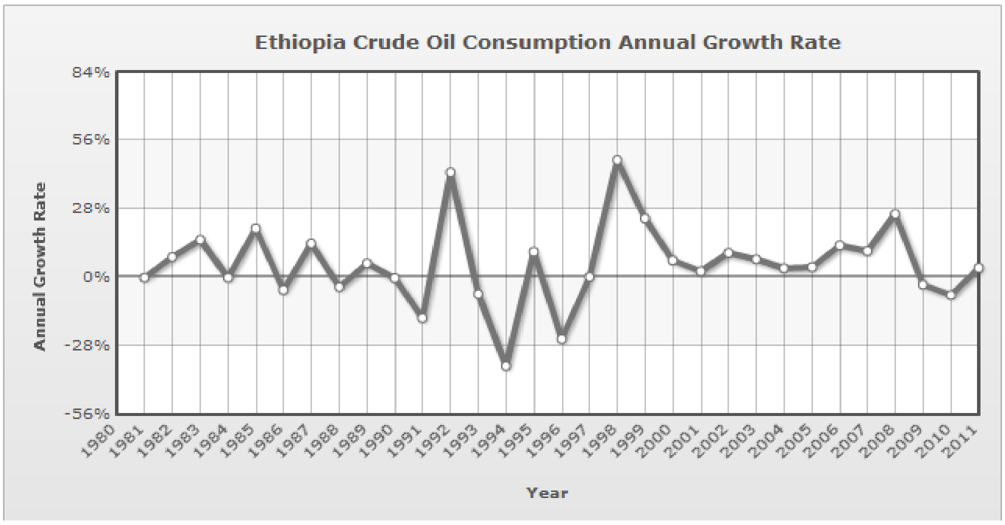
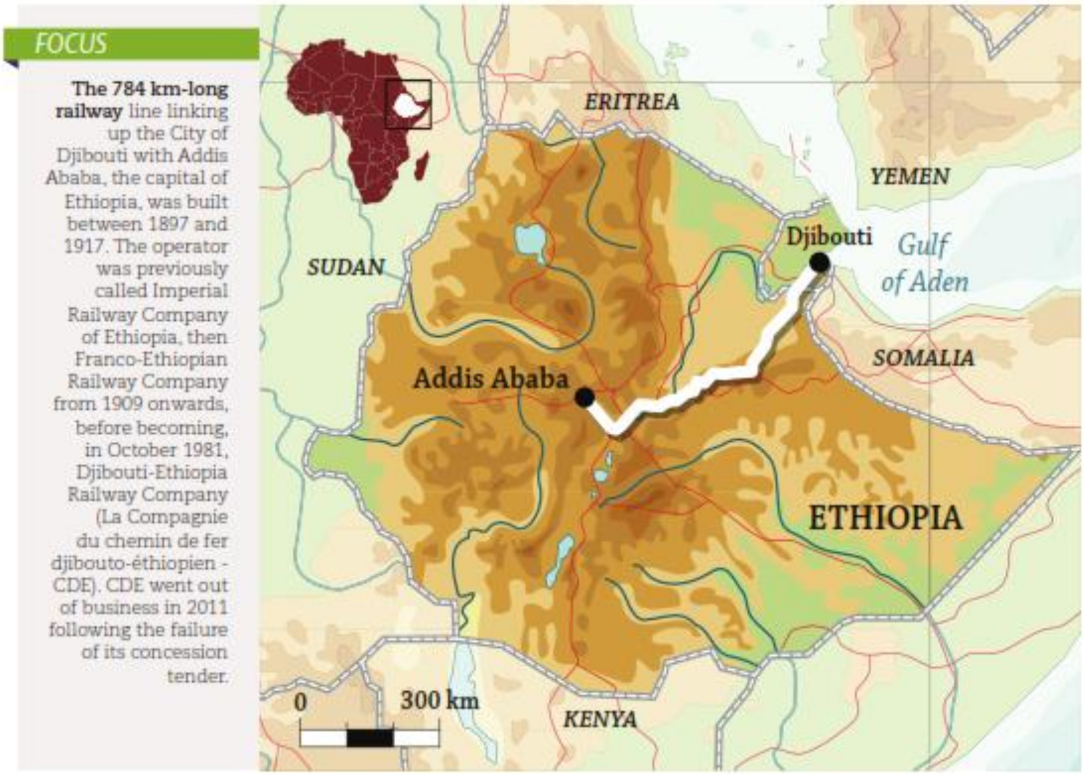


Fig. 1-3. Ethiopian Annual fuel Consumption Rate [EPE]

Ethiopia imports all petroleum and crude-oil fuels it consumes, and the transportation of consumable fluids has been carried out by road transportation using various capacity fuel trucks since the public company, *la Compagnie du chemin de fer djibouto-éthiopien* (CDE) impasse by 2000. **As per** United States Energy Information Administration accepted by EPE, the import volume has been increasing over the past seven years at an average rate of 6.4% per year and the total increase was 44%. The increase in terms of value, however, has been in many folds with an average growth rate of 28% per year and total increase of about 296% (i.e. almost three folds) during the same period. The CDE railway concession would also provide Ethiopia with a less costly means of transportation when compared with trucking, and more generally enhance the country's overall transport capacity. It was in this context that the Djiboutian and Ethiopian authorities decided to grant an operating concession for the CDE railway. Subsequent to the decision to rehabilitate the CDE, additional evidence became available which tended to indicate this had been an appropriate decision. Broadly speaking, this offered a major cost savings opportunity.


FOCUS

The 784 km-long railway line linking up the City of Djibouti with Addis Ababa, the capital of Ethiopia, was built between 1897 and 1917. The operator was previously called Imperial Railway Company of Ethiopia, then Franco-Ethiopian Railway Company from 1909 onwards, before becoming, in October 1981, Djibouti-Ethiopia Railway Company (La Compagnie du chemin de fer djibouto-éthiopien - CDE). CDE went out of business in 2011 following the failure of its concession tender.

Fig. 1-4. Ethiopian NR existing Route [ERC]

According to ICA (2007-2011),

- *Roads needed full rehabilitation every 7 to 10 years, compared to 15 to 20 years for railroads.*
- The cost of transport by truck USD 42.80 per ton, whereas a cost of USD 15.30 to USD 35.60 by rail considered achievable.
- Major savings could also be realized through road maintenance and rehabilitation works since it is studied that with a 30 ton truck yearly causes as much road surface damage as 240,000 cars
- The rehabilitation of the CDE in Ethiopia was important since the country's demand for fuel has been growing from 12%-14% annually and also could also reduce the volume of petrol imports for freight carriers and limit carbon dioxide emission levels. According to Pozzo di Borgo - ICA (2011), a railroad's energy consumption and its carbon footprint could be respectively 75% and 85% lower than that for highway.

Lateral fluid sloshing during turning and sudden line change maneuver is the main cause for low rollover threshold while longitudinal fluid sloshing due to braking or accelerating maneuvers can cause yaw instability or loss of directional control. Most heavy vehicle and freight wagon accidents result from maneuver induced instabilities, such as roll instability and yaw instability. Rollover is the most dangerous mode of instability, which may develop during cornering, lane change, or braking in a-turn maneuvers by the centrifugal forces, the rollover accidents account for nearly 67% of all the serious vehicle and train crashes involving liquid cargo tank transporting [6]. The yaw instability, caused by braking and steering maneuvers coupled with lock-up of axle wheels, may be classified into three different types:

(i) Jackknifing or extensive wagon yaw motion, which may occur when the wagon's rear axle wheels experience lock-up;

(ii) Vehicle / wagon swing or yaw motion, which may occur when the trailer's axle wheels experience lock-up; and

(iii) Snaking or vehicle / wagon Lateral oscillation, which is inherent and may be easily excited by rapid steering inputs or external perturbations at high speeds [7, 8].

For investigation of longitudinal dynamic systems it is very useful to have a viable simulation model of a system under study. Such a model can contribute valuable insights which may be difficult or impossible to obtain by direct observations of the actual system. Multi-body simulation (MBS) is a software tool for computer aided engineering (CAE) that is a method of numerical simulation in which multi-body systems are composed of various rigid or elastic bodies. Connections between the bodies can be modeled with kinematic constraints (such as joints) or force elements (such as spring dampers).

This is the principal reason of attempting to simulate the longitudinal dynamic of railway trains; actual measurement of dynamic effects in trains is both costly and difficult. Practical interest in longitudinal dynamic centers on very long trains since dynamically induced forces in such trains present serious operational problems. A long train may consist of 150 or more wagons. The corresponding model is a nonlinear system of very high order, 300 or more. Solution of such systems by numerical integration package program is prohibitively expensive. Cost has been a major deterrent to simulation of train dynamics. Progress has been made with specially developed numerical integration methods but the cost of such simulation is still very high. Simplifying the model to a completely linear system eases the computation requirements considerably, but unfortunately eliminates the most important features of the train. Simulation is the solution method developed specifically to solve the above problems that seems applicably more efficient than other programs which uses the conventional integration routines.

1.2. Statement of the Problem

Transporting of fluid freights like natural oil, crude oil, jet fuel, edible oil, kerosene and industrial chemicals is a critical issue in our country and it requires a special care since we are importing most of the fluid resources, chemicals and industrial products from abroad in an increasing demand. Transportation of bulk volume of fluids should consider the displacement, cohesion, vibrating, sloshing properties and characteristics of the fluid that probably may lead the vehicle to overturn and to a sudden drop from the running track (derailment). Moreover, fluids in bulk volume transported by a train wagon lead the vehicle to jerky motion and derailments. We are transporting the fluids by cargo cars that could be stated as uneconomical because it requires:

- Higher transporting cost,
- Higher man power cost,
- Higher shipping cost
- Higher road maintenance and time cost

Also it is unsafe to protect from theft and robbery. In Ethiopia, cargo transportation is not totally in a uni-direction road thus it is interrupted by other land vehicles as a traffic volume is going crowded day to day. On the other hand, trains are running on their guided way safely without interruption.

It is the first time that our country is decided to experience transporting of crude-oils and petroleum fluids from port to capital city by train wagons. Therefore it is very important to show the sloshing behavior of fluids during transporting motion. The country demand for fuel has been growing from 12% - 14% annually and the alternate transportation system along with the fuel road trucks, the tank cars are imported to support the fluid especially the petroleum transportation from port to depots and to the factories. The railway accidents have been directly related to the sloshing motion of the liquid content inside the container, thus, it is important to understand if and how the running safety can be affected by the behavior of the fluids during motion.

The case of longitudinal dynamic behavior during train motion can’t be described and observed in laboratory experiments; that is why there is no such a research workshops in our country. Thus, this research result has been decided to be conducted by a multi body simulation analysis using computer programs.

1.3. Objective of the research

The objective of this research was studying the motion behavior of a two bogie fluid wagons running on the rail track so as to identify the risk factors when transporting the fluids by freight wagons focusing on the longitudinal and curving motion characteristics. The aim of this paper therefore, was modeling of a railway tank wagon partially filled with fluid, analyzing the derailment and the rollover cases by determining the critical combinations of track curvature, vehicle speed and tank fill level; also, this study quantifies the impact of neglecting the effect of fluid-sloshing in evaluation of the running safety. The Objective extended to show the cost of the wagon emphasizing the advantage of manufacturing the wagon locally by explaining the basic materials and the manufacturing methods.

The general objective of this research was studying the overall fluid freight transportation characteristics in exact visualized modeling and selecting the appropriate fluid tank shape as well as dimension from standards considering that the rail fluid wagon is going to be one mode of the fluid transportation in Ethiopia. Whereas the specific objective of this study was:

- To study the optional shapes and materials of the available fluid tank wagons so as to model the selected wagon using appropriate modeling / design software.
- To simulate fuel sloshing in a cylindrical tank subjected to longitudinal, and combined longitudinal and lateral acceleration at different fill level by using the latest version of ANSYS -FLUENT software.
- To analyze both the static and the dynamic loading calculations and use the result parameters as input to software packages showing graphical, plot and tabulation reports.
- To optimize the cost of a cylindrical fluid wagon by analyzing the Manufacturing the cost break down and the advantage of the technology adaptation,
- Showing the simulated motion characteristics of fluid transportation and to put the parameters of braking and curving safety in unstable/sloshing load freights.

1.4. Research Methodology

In this particular research study, the methodologies were incorporated the primary as well as the secondary data collection of the specification of the recently arrived fluid wagon, Visualization of wagon condition, photographing, etc. these techniques have been used effectively so as to use their information in analyzing the problems and solving the cases on mechanical or mathematical representation of the fluids inside the tank container during train running on combined straight-curved track and also to model the wagon shape accordingly. Moreover, the CFD (Computational Fluid Dynamics) solution results by using the multi-body-dynamic simulation (MBS) methods showing the real sloshing characteristic of fluids inside the container has been included in this research. Thus, the main tasks in this thesis can be roughly described as follows:

- The wagon and the tank shape as per the standard dimension have been modeled by using Solidworks-2014 modeling Software. Then it helps to visualize the partially filled fluid wagon and it may be an input-model for simulation analysis in SIMPACK and Ansys-Fluent packages.
- Solving of the nonlinear fluid slosh equations in an Eulerian mesh after representing the model as mechanical modeling to determine dynamic fluid slosh loads caused by the dynamic motion of the wagon has been solved by ANSYS Release 14.5 fluent package.
- Studying the cross-sectional shape characteristics of the fluid tankers regarding the mass center shift behavior of the fluids in motion has been performed by comparing the most commonly used tank cross-sections in liquid bulk transportation.
- Cost comparison and optimization of the fluid tank with respect to the manufacturing methods and capacity has been performed to emphasis the advantage of reverse-engineering in technology transfer and in hard-currency savings.

1.5. Significance /Importance of the Research

Since our country is importing fluids like fuel and industrial chemicals in bulk volume from abroad, transportation is the main problem to transfer the fluids from port to the depot and to the factory sites; then, studying the motion property of the sloshing fluids is necessary to make remedies before the loss of properties, manpower, wealth and time. As a research, this paper will be collected to be kept in ERC future research center. Since our country is just practicing the modern rail transportation sector, there has to be a lot of research-studies to be done in the area, it will give a comprehensive starting point and reference for further research and studies.

1.6. Limitation of the Research

The time period scheduled to complete the thesis refrained not to incorporate the different motion cases like full tank loading, the behavior of motion of fluid train in switches and motion in gradient tracks and the combination of wagon tracking characters. Actual test limitation has been faced because there is lack of resource and there is no simulation laboratory to take test regarding this research study. Moreover, the wagon not yet started the transportation service at the time of this study therefore the field observation can't be incorporated.

Moreover, there was no railway research center to get accessible information and to collect the required data in organized way.

1.7. Scope of the research

This study covers studying the displacement characteristic of fluids during transporting in bulk volume by train wagons focusing only on how the load shift due to the sloshing behavior of fluid affects the motion and the braking of train. Considering that the tank is firmly attached with a two bogie / four axle bedless wagons.

Thus this study basically concentrates on studying the behavior of the fluid wagon motion, sloshing effects, along with suggesting the wagon manufacturing reasons regarding analytical cost optimization, and showing the simulation parameters with results of wagon motion along a minimum allowing curvature in three different fluid fill-levels.

CHAPTER TWO

LITERATURE REVIEW

In the current chapter, the summary of the literature surveyed during the course of this research has been presented. This survey of literature is expected to provide the background information and thus to select the objectives of the present investigation on sloshing.

2.1. Introduction

Sloshing in tanks has received much attention over the years since the mid-1950s (Graham and Rodrigues, 1952). The major field of interest was initially aeronautics, where the motion of fuel in the fuel tanks would affect the dynamics of a plane. Fuel in space rockets became a further field of focus. More recently, the motion of liquids, including fuel, in numerous maritime applications and its structural and destabilizing effects attracted much attention. Further fields of interest include the aerodynamic and seismic stabilization of tall structures and the acoustical effects of fuel sloshing in rail fuel tanks. This section of the thesis provides an overview of some of the major fields of interest either utilized or examined in this work. This survey of literature is expected to provide the background information and thus to select the objectives of the present investigation on sloshing in commonly used geometry storage tanks. Some Computational as well as Numerical work has been investigated throughout this work and utilized here.

2.2. General

While the train is running along the truck, each of its wagons not only moves in the longitudinal direction but also has motion in the lateral and vertical directions. In the case of the longitudinal dynamics being the main focus of the study, the effects of the lateral and the vertical dynamics assumed to be negligible and every wagon in the train can be viewed as a mass point [24]. The transient position is designated by its algebraic arc length coordinate. The applied forces on wagon 'I' with mass 'm_i' are made up of the basic resistance 'f_i^w', the gradient resistance 'f_i^g' resulting from the slope of the track, , and the curving resistance 'f_i^r' and its coupler forces. The detail about these forces will be discussed in the following sections. The equation of the longitudinal motion of wagon 'i' can be written as:

$$m_i \ddot{S_\imath} = f_i^w + f_i^g + f_i^r + (f_i^c - f_{i-1}^c)$$

Where 'S_i' is its arc length coordinate and 'f_i^c' is the force of the rear coupler on wagon i.

2.2.1. Dynamic sloshing forces

The magnitudes of forces in the steady and transient state are derived from the Water pressure distribution over the wetted boundaries of the baffled as well as the clean bore tanks. The resultant slosh force are computed from the distributed pressure through integration over the wetted area of the wall cell, such that

$$F_x = \sum_{C}^{wetarea} P_C \overrightarrow{A_C} . \vec{\imath}$$

$$F_y = \sum_{C}^{wetarea} P_C \overrightarrow{A_C} . \vec{\jmath}$$

$$F_z = \sum_{C}^{wetarea} P_C \overrightarrow{A_C} . \vec{k}$$

Where$F_x, F_y, and\ F_z$ are the resultant slosh forces acting on the tank wall along the fixed x, y and z axes due to pressure P acting on cell "c" with area vector A_c. 'i', 'j' and 'k' are the unit vectors in the x, y and z directions respectively. [3]

2.2.2. Sloshing moment

Apart from the dynamic slosh forces, the moment caused by variation in the cg coordinate are known to be significant factor in the view of the directional response of the vehicle. The roll, pitch and yaw moment about point "o" located at the bottom of the tank directly beneath of origin are obtained upon integrating the moment corresponding to each cell over the wetted area:

$$\vec{M} = \sum_{C}^{wetarea} \overline{r_c} \times F_c$$

Where F is the force vector caused by a cell "c" on the boundary, of cell "c" with respect to "o" and M is the moment vector about point "o". The coordinate of this point "o" are (0,-r, 0), where R is the tank radius. [3]

2.3. Computational Fluid Dynamics

During the last three decades, Computational Fluid Dynamics has been an emerged as an important element in professional engineering practice, cutting across several branches of engineering disciplines. Computational fluid dynamics (CFD) is the branch of heat transfer and fluid mechanics that uses algorithm code and numerical method to analyze problem that involve fluid flow by means of computer based simulation.

Computational fluid dynamics is the science of predicting fluid flow, chemical reactions, heat transfer, and related phenomena by solving numerically the set of governing mathematical equations[4]:

- Conservation of mass
- Conservation of momentum
- Conservation of energy
- Conservation of species
- Effect of body forces

As we know the fluid flow and heat transfer are governed by basic fundamental equations which are in partial differential (mostly in non-linear) form so analysis or prediction fluid flow process can be done in following ways effectively:

2.3.1. **Experimental Approach**: In an experimental approach, analysis is done in prototype. The most reliable result about any physical process is often given by actual measurement. An experimental approach involving full-scale equipment can be used to predict how identical copies of equipment would perform under the same condition. But the cost of the experimental setup in most of cases is quite high and expensive and often impossible. Despite of the many drawbacks like high cost, time, feasibility and extrapolation of result, it has one big advantage that experimental approach is capable of producing the most realistic result.

2.3.2. **Analytical Approach**: In analytical approach governing equation of the model is solved mathematically by using boundary condition. But there is little hope of predicting many phenomena of practical interest by using classical mathematical method of solving partial differential equation. The big advantage of analytical approach is that “clean” general information can be obtained. This approach is quite useful in preliminary design work. The limitation of analytical approach is the complexity of with experimental is about governing equation and complexity of the geometry.

2.3.3. **CFD or Numerical Approach**: The drawbacks of experimental and analytical approach are encountered by using numerical method or CFD. In CFD the nonlinear partial differential equation is solved by numerical techniques. In this approach the non-linear partial differential equation are discretized into linear algebraic form of equation over a control volume by finite difference, finite volume and finite element methods. Then set of linear algebraic equation are solved iteratively by numerical technique such as gauss sidle method and TDMA method. CFD analysis complements testing and experimentation by reducing total effort and cost required for experimentation and data acquisition.

The advantages of CFD are it can solve non-linear P.D.E., complicated physical phenomena can be treated, time evaluation of flow can be obtained and we can simulate the ideal conditions. There are no such drawbacks in CFD approach but there are some errors in this process such as truncation error, round-off error, and machine error etc. which affect the result to some extent.

As already explained that, in computational fluid dynamics the non-linear partial differential are discretized into linear algebraic set of equation. Discretization is the method of approximating the differential equation by a system of algebraic equation for the variables at some set discrete location in space and time. The discrete locations are grid, mesh point or cell. By doing discretization continuous information from the exact solution of PDE is replaced with discrete value. Discretization is done by using finite difference, finite volume and finite element methods. The brief introduction to above method is given below:

- **Finite difference method**: FDM is the oldest of the three methods. This technique published as early as 1910 by L.F. Richardson. In this method domain is discretized into series of grid point i.e. Structured i, j, k, grid is required. The non-linear partial differential equation discretized by Taylor series of expansion into linear algebraic equation.

- **Finite volume method**: This is the "classical" or standard approach used most often in commercial software and research codes. In FVM method, the partial differential equation is discretized over a control volume by using gauss divergence theorem. Control volume is obtained by dividing the domain of interest and discretized the governing P.D.E over each control volume which results in a set of algebraic equation which can be solved iteratively. In this approach the value of variable stored at center of control volume. FVM enjoys an advantage in memory use and speed for very large problems, higher speed flows, turbulent flows, and source term dominated flows (like combustion).

Advantage: Basic FV control volume balance does not limit cell shape; mass, momentum, energy conserved even on coarse grids; efficient, iterative solvers well developed.
Disadvantages: false diffusion when simple numeric is used.

- **Finite element method**: This method is popular for structural analysis of solids, but is also applicable to fluids. The FEM formulation requires, however, special care to ensure a conservative solution. The FEM formulation has been adapted for use with the Navier-Stokes equations. In this method, a weighted residual equation is formed:

$$R_i = \iiint W_i \, Q \, dV^e$$

Where R, is the equation residual at an element vertex i, Q is the conservation equation expressed on an element basis, W is the weight factor and dV is the volume of the element. Advantages: highest accuracy on coarse grids. Excellent for diffusion dominated problems (viscous flow) and viscous, free surface problems.
Disadvantages: slow for large problems and not well suited for turbulent flow [11].

2.4. Fluid tank Designation and Specialized applications

A tank container, also known as ISO tank, is a specialized type of container designed to carry bulk liquids, such as chemicals, liquid hydrogen, gases and food-grade products. Both hazardous and nonhazardous products can be shipped in tank containers. Generally throughout the world, tank cars are known as tank wagons or tanker wagons. In most countries the tank wagons are commonly a two bogie with four axle vehicles however in the United Kingdom we can rarely found traditionally two-axle tank wagons. Some long-wheelbase four-wheelers are still in use but bogie vehicles are now used.

Fig. 2-1. Model of fuel tank-rail wagon [26]

2.5. Tank car Material and Specialized Applications

In rail transport, the Standard Petroleum tank Wagon is a type of unpressurized tank car manufactured by sheet metals in cylindrical shape. The tank wagon common used in Europe and North America is designated as DOT-111. The tank cars built to this specification must be circular in cross section, with elliptical, formed heads set convex outward. They have a minimum plate thickness of 7/16 inch (11.1 mm) and a maximum capacity of up to 34,500 US gallons (131,000 L). Fuel tanks are usually constructed from carbon steel plate by fusion welding [26].

The GN-70 tank car, that ERC imported from China for the purpose of transporting the expected petroleum based fuels for the countries energy consumption is a standard gage fuel transporting wagon suitably utilized for crude, heavy diesel fuel transportation.

Table 2.1. Tank wagons and specialized Applications

Wagon Designation	Special Application
DOT-111, Me307 and MC 312 tank cars	which are designed to carry liquids, such as denatured fuel ethanol, crude oil,
DOT-112 tank cars	are used in North America to carry pressurized gases
DOT-114 tank cars	are used in North America to carry pressurized gases
DOT-113 tank car, AAR-204W tank car and AAR-204XT	Tank cars of this type are designed to carry cryogenic (low temperature liquids) liquid Hydrogen (LH2). North American cars are classified as DOT113, AAR204W, and AAR204XT
Milk car	A milk car is a specialized type of tank car designed to carry raw milk between farms, creameries, and processing plants. Milk is now commonly chilled, before loading, and transported in a glass-lined tank car. Such tank cars are often placarded as "Food service use only”

2.6. Review of other researchers work summary

Liquid sloshing in 3-D water storage tank with and without baffles is investigated. It is evident from the CFD transient simulations of liquid interface carried out at various time steps for both configurations (with and without baffle) of tank that impact of sloshing reduces significantly by the use of baffles. As per the analysis of many researchers, it can be seen that sloshing loads will be higher if the tank is excited by natural frequency near resonant condition, liquid sloshing will become violent, show overturning, and create severe impact on the top wall of the tank. To reduce the impact of sloshing forces in tank wall, baffles are provided inside the tank, which can work as a damper and sufficiently reduce the amount of slosh waves. It can be predicted that the larger the fill level of tank, greater the complexity of liquid sloshing.

2.6.1. Computational methods review

K.M.Tehrani et al. [12] studied sloshing of fuel in a partly filled cylindrical tank equipped with baffle. In this study, three-dimensional transient analysis are performed under varying magnitude of constant longitudinal, lateral and combination of longitudinal and lateral acceleration of tank, and two different fill volume using FLUENT software. The result of investigation are presented in term of amplification factor of slosh forces and moment and variation in the mass moment of inertia of fuel within a clean bore tank and a baffled tank, for two different magnitude of acceleration excitation and two different fill volume. The result of above study clearly shows that amplification factor of forces and moment for clean bored tank is about 2 and amplification factor reduces significantly by inserting transverse baffle.

D.Takabatake et al. [13] has studied about many structural damage caused by liquid sloshing. They observed many petroleum tanks were damaged by sloshing during 2003Tokachi-oki, Japan. Large earthquakes are predicted to occur within 50 years, which will cause the similar damage. They developed a splitting wall as a new sloshing reduction device. Model experiments and numerical simulations are performed to investigate the effect of the device. The experimental results indicate the proposed device is effective to reduce sloshing against sinusoidal input motion. They also perform numerical study to simulate the experimental result. Both experimental and numerical results are almost same. Based on the numerical simulation, the proposed device can be also effective against earthquake ground motion.

Vaibhav singal et al. [9] studied sloshing phenomenon in a partially filled kerosene tank using volume of fluid (VOF) multiphase model with and without the use of baffles. Computational study was done using Finite volume method in ANSYS-FLUENT software. Result shows that sloshing in the fuel tank was effectively reduced with the use of baffles in the tank.

S. Rakheja et al. [10] studied effectiveness of different design of baffle, including lateral, oblique, conventional and partial under longitudinal and lateral acceleration for different fill levels in a 3-D truck tank. This analysis was done using ANSYS-FLUENT software with volume of fluid (VOF) model for tracing of interface between two fluids. The result shows that the conventional lateral baffles are more effective to fluid slosh under longitudinal acceleration only while the oblique baffle helps to reduce both longitudinal as well as lateral slosh forces

Y.G. Chen et al. [15] simulated sloshing in a partially filled tank excited by dynamic load to calculate the impact pressure. For free surface representation, Reynolds-averaged Navier–Stokes (RANS) is used which a two-fluid approach based on a level set method. For numerically investigation purpose, rectangular tank was excited by horizontal harmonic motion and harmonic rolling motion. Simulation is done for different filling levels and excitation frequencies. The computed results were compared with experimental data and show that simulation of dynamic pressure loads exerted on the tank walls and ceiling can be done very effectively with numerical methods.

Kingsley et al. [21] studied about design and optimization of 3-D rectangular container for sloshing and impact using VOF technique. They performed the investigation using numerical simulation as well as experimental validation. For numerical simulation k-Ɛ turbulence model for viscous effects and an acceleration user defined function (UDF) input was imposed for motion of tank.

Liquid cargo tanks are designed with either external ring stiffeners or internal transverse baffles to achieve enhanced integrity of the tank structure in accordance with current standards. The internal baffles have proven to be highly efficient in suppressing the fore-aft motion of liquid cargo within the partly-filled tank. A few studies analytically, using a mechanical analogy modeled and or experimentally investigated the damping effectiveness of such slosh suppression devices [18, 19]. Anti-slosh devices such as ring baffles, truncated perforated cones and flexible baffles, have been explored since early 1970“s [18] by National Aeronautics and Space Administration (NASA) to mitigate propellant sloshing induced by the launch vehicle tank motion. To achieve improved braking performance, while the analysis employed kineto-static fluid motion. The reported study concluded that equal compartment lengths yield minimal longitudinal load shift under straight-line braking. **Strandberg** [19] experimentally evaluated the effectiveness of different longitudinal anti slosh baffle arrangements within scaled tanks.

Salem et al. [20] studied rollover stability of a partly-filled elliptic tank vehicle using a pendulum model to simulate fluid sloshing. Although this study predicted considerably accurate values of rollover threshold, identification of parameters for the analogous slosh model was extremely challenging. Moreover slosh models based on pendulum analogy are limited to linear sloshing scenarios only. Most of these analytical and mechanical analogous slosh models were limited in their application since they could simulate only small amplitude sloshing.

2.7. A Generic Tank Cross-Section and Shape Optimization

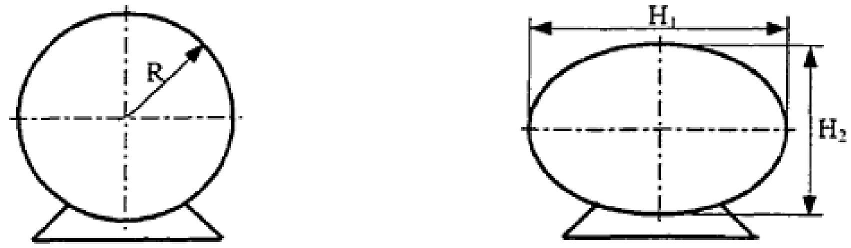
It has been identified that maneuver-induced liquid cargo motion in a partly-filled tank wagon poses a serious threat to the stability and controllability of the vehicle. Optimal tank cross-sections are realized to achieve both low *c.g.* height and minimal lateral load transfer for varying fill volumes. High center of mass (cg), design of the saddle-mounted tank together with moments induced by cargo shift, lead to relatively lower stability and control limits of such vehicles. Even a reasonable maneuver could yield tank-wagon instability and thus a rail accident. Accidents involving such wagons are generally associated with highly unreasonable risks to motion safety, safety of road users and the environment, when flammable and hazardous cargoes are involved. Rollover, jackknifing and trailer swing are some of the instability modes that have been attributed to liquid cargo slosh within a tank vehicle [15, 16]. Amongst all these instability modes, rollover accidents have been reported most frequently, although the eventual rollover may be caused by yaw instability. The rollover accidents account for nearly 67% of all the serious single vehicle crashes involving liquid cargo tank vehicles [17]. It has been further reported that the injuries and fatalities among the truck drivers attributed to rollover accidents are in the order of 45% and 52%, respectively [17]. In a study by Battelle, it has been shown that partial fill in a road tanker accounts for relatively greater rollover incidents

The roll stability of partially-filled tank vehicles is strongly influenced by both the c.g. height of the tank trailer and magnitude of liquid load. Transfer in a complex manner. Circular cross-sectional tanks (Me 307 and MC 312), employed in transportation of general-purpose liquid products, yield high c.g. location, but relatively less load transfer under partial fill condition and application of a lateral acceleration field. Modified-oval cross-sectional tanks (MC 306), used in delivery of fuel oils, yield relatively lower c.g. height. But considerably larger lateral load transfer under a lateral acceleration disturbance, when compared with that encountered in partially-filled circular tanks of nearly identical cross-section area, especially under low fill volumes. A circular cross-section tank is thus considered to provide relatively higher roll stability under low fill volumes, while a modified-oval geometry yields better roll stability under high fill volumes [18].

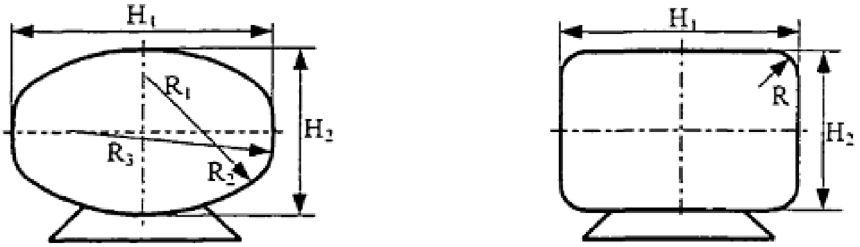
2.8. Lateral Liquid Load Shift Analysis of Conventional Tanks

Movement of liquid cargo within a partly-filled tank is strongly dependent upon its cross-section, fill volume and severity of the vehicle maneuver. Tanks with circular, elliptic, modified-oval and modified-square cross-sections, shown in Figure 2.2, are mostly commonly used for bulk transportation of chemicals, fuel oils, etc. Among these, the circular and modified oval tanks are by far the most popular tank cross-sections used for transportation of general-purpose liquid products and fuel oils, respectively. These cross-sections exhibit symmetry about the vertical and horizontal axes, and their geometry can be described by a number of parameters, ranging from 1 to 5. A circular cross-section can be described by its radius (R) alone, while the elliptic cross-section is defined by its major and minor diameters (H, and Hl). A modified-square tank is defined by three parameters: width (HI), height (H1) and blend radius (R). A total of five independent parameters are required to describe the modified-oval cross-section. These include radii of the top/bottom (R,) and side (R) surfaces, blend radii (R2), overall height (H1) and overall width (HI).

The center of gravity (c.g.) of the liquid bulk within a partly-filled tank experiences lateral and vertical shifts under vehicle roll and lateral acceleration encountered in a turning maneuver. The shift in the c.g. coordinates yields a destabilizing roll moment, which contributes to relatively lower roll stability limits of such vehicles. The magnitude of lateral load transfer of liquid cargo within a partly-filled tank depends upon tank cross-section, fill volume and severity of the steering maneuver. In view of vehicle roll stability, each tank cross-section offers certain advantages and limitations related to its geometry [27].



(a) Circular (b) Elliptic



(c) Modified-oval (d) Modified-square

Fig. 2-2. Commonly used tank cross-section in liquid bulk transportation [27]

While wider tank cross-sections, such as modified oval and modified square, yield lower c.g. heights, they cause larger movement of the mass center under partial fill conditions. A cross-section with relatively lower width, such as circular, yields higher c.g. height but lower c.g. shift along the lateral and vertical axes under application of a lateral acceleration field.

CHAPTER THREE

MATERIALS, CONDITIONS, METHODS AND ANALYTICAL MODELS

3.1. Materials

The modeling materials significantly considered and thus they are considered having importance on the modeling and in the dynamic motion analysis are specified as follows:

a) Fluid Wagon

The study was conducted considering the dimension and the parameters of the upcoming Indian made, model GN70 tank wagon attached with two bogies of having two axles each, and the bogies are rigidly attached with the tank wagon. Technical data along with its photo as reached at Dire-dawa rail parking are presented in appendix A.

b) Load

The tank wagon is particularly designed to transport crude-oil and petrol, thus the load that is considered in this study is the petroleum with all its mechanical, tribology and thermal properties. The load shifting behavior during the motion of the container tank and the surge effect of disturbance of this unstable fluid has been considered.

c) Software packages

The study was conducted by using the following modeling, animating, simulating and result solver softwares:

- **Solid-works 2014** – this software is used to model the part design of each of the wagon components and assembly according to the real part mates to show a clear wagon appearance. The modeling of fluid wagon has been shown in fig. A

- **Ansys-14.5 package** – this package is the most recent and famous analysis software well known to solve the structural, meshing, thermal, fluent and other analysis by the method of FEA. In this study this software helps to realize the CFD sloshing dynamic analysis of the petrol fluid during Braking.

- **SIMPACK 9.6 build 93 software**. Is a software tool for Computer Aided Engineering (CAE) that uses Multi-Body Simulation (MBS) method in which multi-body systems composed of various rigid or elastic bodies as well as Connections between the bodies can be modeled with kinematic constraints (such as joints) or force elements (such as spring dampers).

3.2. Conditions

The different reasons may be considered to transport the fluids partially filled inside the tank based on:

- Variation in the product transported – axle load and fluid shift consideration
- Local delivery route and drop quantity – delivery order
- Considering buffering relief gap in fluid disturbance during motion, etc.

The partial filling can be occurred both in constant and in varying payloads. The condition for the case of this study is considering the baffled-wagon is partially filled to a level of 50%, 65% and 80%. Also, the mates between components are normally considered without friction, the running truck is combined of straight – curved with total length of 323m., the gauge of the truck that the wheel-set mates with is standard gauge of width 1435mm. The study has been done for two different cases of acceleration direction and magnitude considering the max allowable Speed of 90 km/hr. (25 m/s) and 120 km/hr. (33.33m/s).

3.3. Methods and Assumptions

3.3.1. Assumptions

The following **assumptions** are employed in modeling the fluid to capture the sloshing and acoustic motions:

a) The fluid is considered to be inviscid-compressible fluid and negligible contributions due to fundamental slosh frequency
b) The motion of the fluid wagon is uniformly accelerated on combined straight and curved track with uninterrupted running. i.e., combined 120m straight and 200m curved track of critical radius of curvature 145m with straight-curve transition length 3m.
c) Entire liquid cargo within partly-filled tanks is assumed to translate as a bulk

d) Angles of the tank roll and the liquid free surface inclination are very small,

e) The viscous forces of the liquid are small compared to the inertial forces,

3.3.2. Methods

The procedural method for this study to reach to the simulation and by then the graphical, tabulated as well as the animation results is shown as the following flow chart.

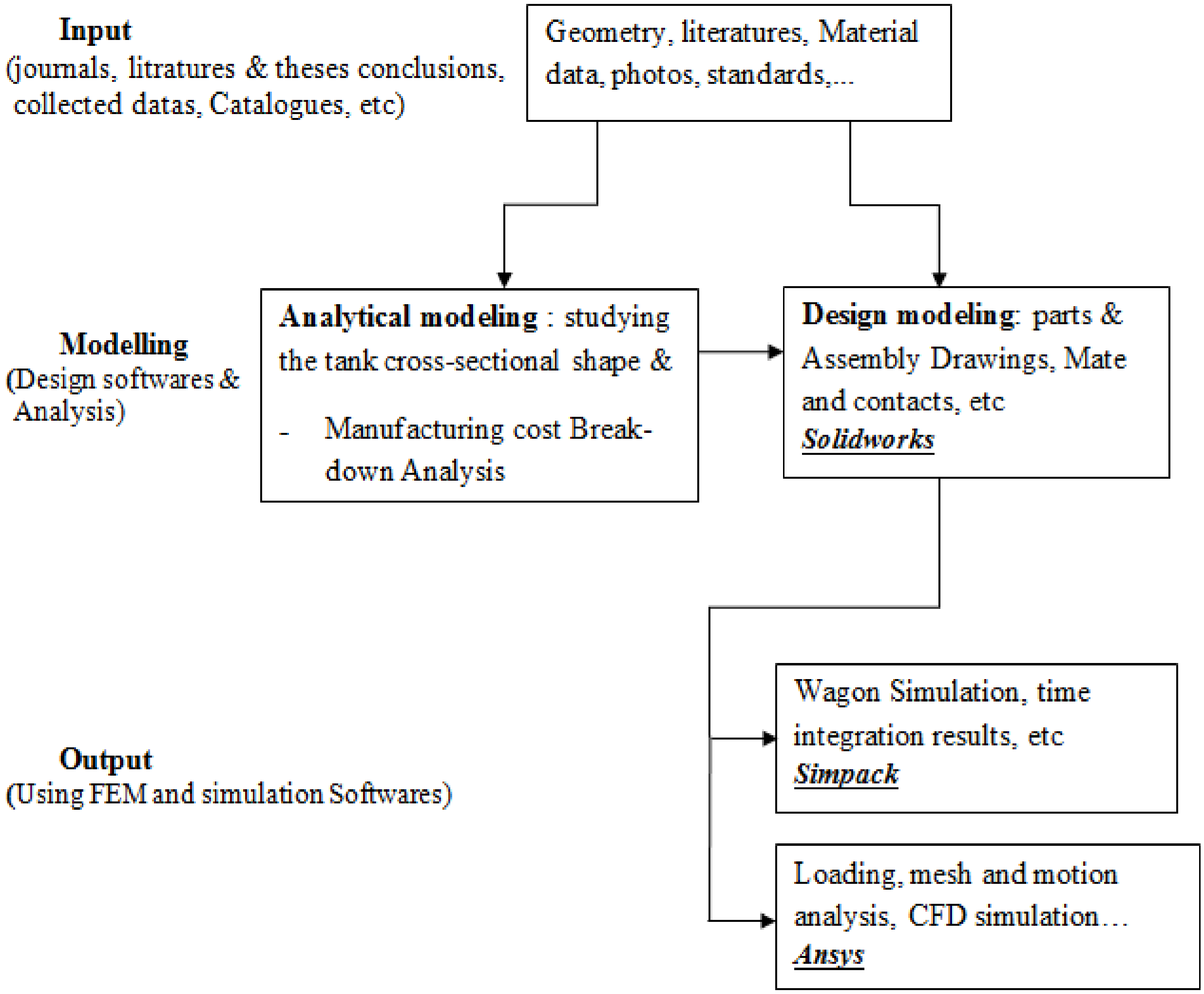


Fig. 3-1. Flow-chart of basic methodology

3.4. Analytical Models

3.4.1. Geometric Model

The physical model of the present study is shown in Fig3.1 the physical model consist a cylindrical fuel tank wagon of a moving freight train, which is partially filled with diesel/Naphtha (ρ =830 kg/m^3, μ = 0.042 kg/m-s). The dimensions of the tank are of 12 m length and 2.6m diameter [5]. The Diesel occupies three different fill-level of the total volume of the space in the cylindrical tank. The remaining part of the tank is occupied with air. Even in the uniform motion (cruising phase), minor disturbing forces also contribute for sloshing. However, in this study we considered only the sloshing due to the straight and curving running of the vehicle. To reduce the sloshing rate **four** similar circular baffles are introduced in the tank so as to reinforce the tank and to reduce the sloshing effects as well. The axis of the radially arranged adjacent baffles coincides with the axis of the tank. The detail various dimensions of the physical model of fuel tank wagon as per of GN70 type China made Ethiopian wagon are given in Fig 3.2.and Fig 3.3

Fig. 3-2.a. Real appearance of GN-70 fluid freight wagon [ERC]

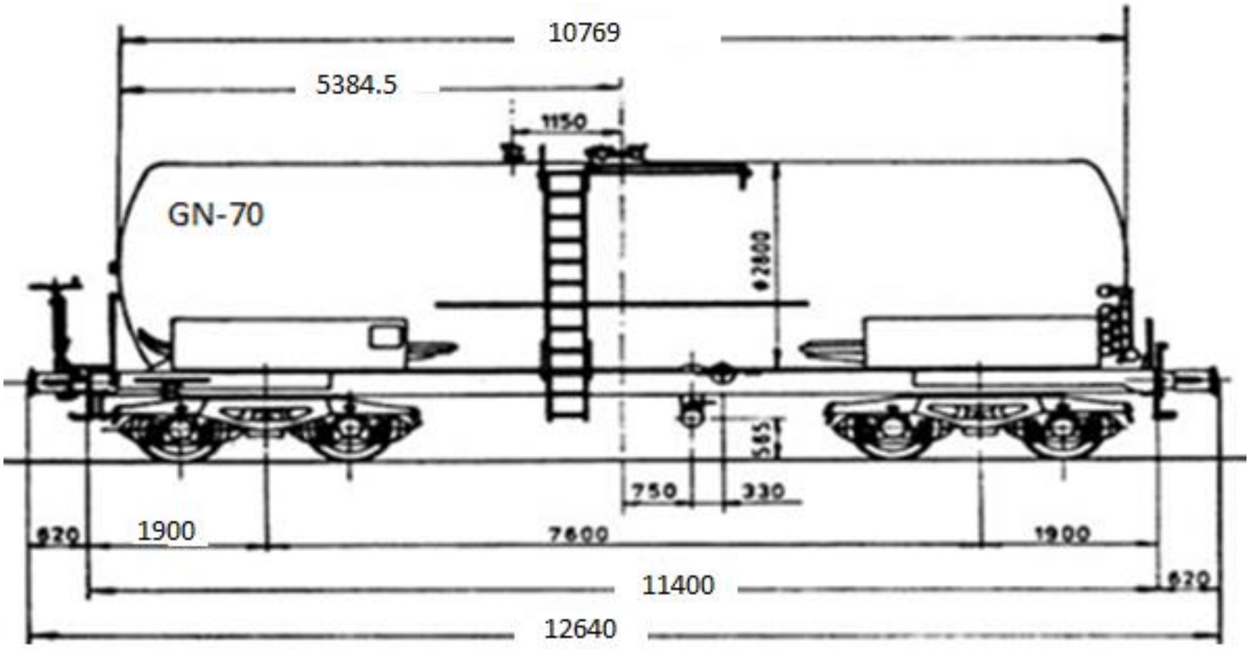


Fig. 3-2.b. Schematic appearance and dimension of GN-70 fluid freight wagon

The following figure is a Silidwork model which has been assembled after designing of each and every parts of the wagon to show the actual appearance of fluid transporting freight wagon as per the actua model of GN-70 fluid wagon.

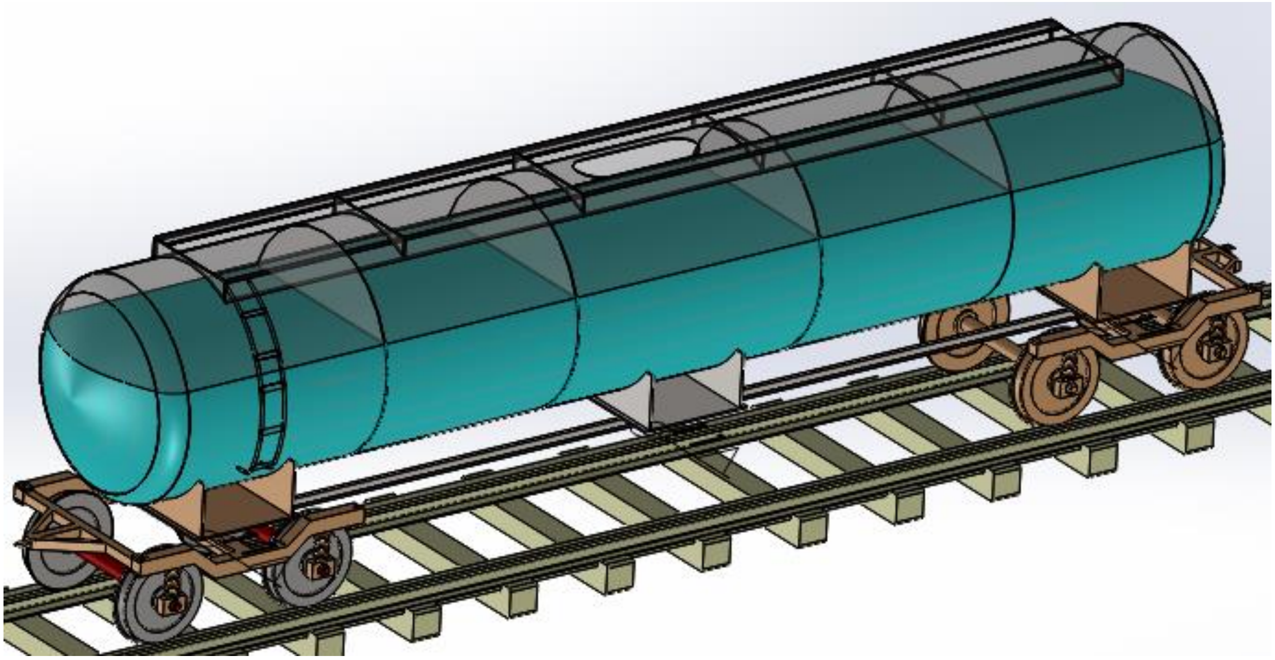


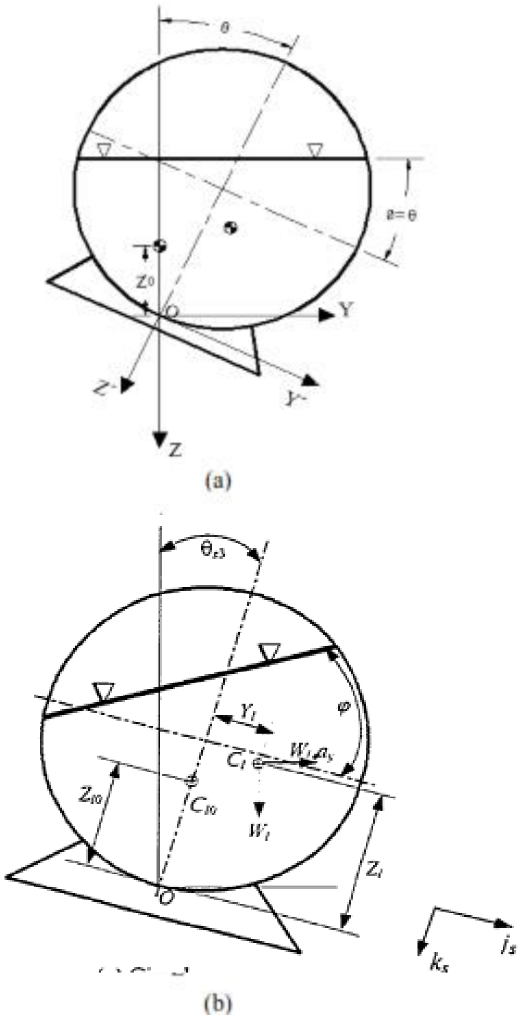
Fig. 3-3. Solid-works modeling of fluid freight wagon

3.4.2 Analytical Model of Cylindrical wagon

Considering equilibrium of forces for an inviscid fluid element inside the partly-filled tank subjected to simultaneous roll motion and lateral acceleration, the free surface gradient could be derived from [23]:

$$\tan \emptyset = \frac{\theta - a_y}{(1 + a_y.\theta)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where a_y vehicle lateral acceleration in g, θ is the sprung mass roll angle in radians and ϕ is the angle between free surface and horizontal axis of the tank. Neglecting roll motion of the tank, the free surface gradient could be directly related to the lateral acceleration, $\tan \emptyset \approx a_y$



(a)

(b)

Fig. 3-4. Translation of center of the liquid wagon under (a) tank Roll and (b) Lateral Acceleration [23]

The **quasi-static** fluid slosh model of the circular cross-section tank is illustrated in Figure 3.4. The free surface gradient, defined in Eq. (i), can be applied to derive the steady state load shift, and slosh forces and moments under roll motion of the tank and lateral acceleration. The model describes the steady-state free surface after the free surface oscillations have completely decayed. The equation of the free surface of the liquid cargo, subjected to roll motion and lateral acceleration in the steady condition could be written as [25]:

$$z = -\left\{\frac{\theta - a_y}{(1 + a_y.\theta)}\right\} y - c \text{ ……………………………….. (ii)}$$

Where z and y are the vertical and lateral coordinates of the liquid particles at the free surface, respectively, $\frac{\theta - a_y}{(1 + a_y.\theta)}$is the free surface gradient and c is the free surface intercept with the *Z-axis*. The equation of free surface of the liquid cargo in the absence of roll motion and lateral acceleration is directly related to the fill height c from the bottom of the tank, 'O':

$$z = -c_o \text{ ………………………………………………………………..…. (iii)}$$

Furthermore, the equation of the circular tank periphery with respect to the body fixed coordinate system is expressed in terms of its radius R as:

$$z^2 + (z + R)^2 = R^2 \text{ ……………………………… (iv)}$$

The intersection points of the initial free surface of liquid cargo on the tank periphery are estimated by simultaneously solving Eqns. (ii) and (iv) or Eqns. (iii) and (iv). The left and right intersection points (y_{l0}, z_{l0}) and ($y_{r0,}$ z_{r0}), are mirror reflection of each other due to the symmetry of circular tank. The fluid volume per unit length of the tank can be evaluated from area integral:

$$V_o = 2\int_0^{y_{ro}} \int_{f_{1(y)}}^{c_o} dzdy \text{ …………………………… (v)}$$

Where$V0$ is the fluid volume per unit length of the tank in absence of roll motion and lateral acceleration, function f_1(y) describes the tank geometry, and $c_0$defines the domain of integration along the z-axis. The volume of fluid per unit length of the tank subjected to roll motion and lateral acceleration can be derived in a similar manner by considering coordinates of the intersection points of the deflected free surface (y_{l},z_{l}) and (y_{r},z_{r}):

$$V = \int_{y_l}^{y_r} \int_{f_{1(y)}}^{f_{2(y)}} dzdy \text{ ……………………………(vi)}$$

Where V is the fluid volume per unit length, f_2(y) is the function of liquid cargo free surface derived from the Eqn. (iii), and f_1(y) defines the domain of integration along the z-axis. y_l and $y_r$are the y-coordinates of the left and right intersection points of the free surface with the tank periphery. Considering that the fluid volume per unit length remains constant, $V=V0$, the intercept c is subsequently computed by minimizing the volume error, $\varepsilon = |V_o - V|$

The coordinates of the left and right intersection points of the free surface (y_{l},z_{l}) and (y_{r},z_{r}), are derived from simultaneously solutions of Eqns. (ii) and (iv). The coordinates of the center of gravity (cg) of the deflected liquid cargo are then derived from the following moment integrals, which directly defines the steady-state load shift:

$$Z_{cg} = \frac{1}{V}\int_{y_l}^{y_r}\int_{f_1(y)}^{f_2(y)} Z\, dzdy \text{………………………… (vii)}$$

$$Y_{cg} = \frac{1}{V}\int_{y_l}^{y_r}\int_{f_1(y)}^{f_2(y)} Y\, dzdy \text{………………………… (viii)}$$

Where (Y_{cg},Z_{cg}) define the coordinates of the cargo cg with respect to the tank base, ‘O’. The slosh forces and roll moment are subsequently derived from the mass of liquid cargo, acceleration excitation and the cg coordinates as:

$$F_y = ma_y;\text{ and } F_z = ma_z \text{ ……………………..(ix)}$$

$$M_x = \left(ma_y \cos\theta\right)Z_{cg} - \left(ma_y \sin\theta\right)Y_{cg} + (ma_z \cos\theta)Y_{cg} + (ma_z \sin\theta)Z_{cg} \text{ ……. (x)}$$

Where$a_z$is the acceleration due to gravity, m is the mass of the liquid cargo, F_y *and* F_z *are* the steady-state lateral and vertical forces, respectively, and M_x is the steady-state roll moment about the tank base “O”. This roll moment is an additional overturning moment imposed on a partly filled tank vehicle, which is not observed in conventional rigid cargo vehicles.

3.4.2. Computational Model

ANSYS Fluent CFD software consists of broad physical modeling capabilities needed to model flow, heat transfer, turbulence, and reactions for industrial applications. Special models that give the software the ability to model aero acoustics, in-cylinder combustion, turbo machinery, and multiphase systems have served to broaden its reach. Due to mesh flexibility offered by Fluent, flow problems with unstructured meshes can be solved easily. Fluent supports triangular, quadrilateral meshes in 2D-problems and tetrahedral, hexahedral, wedge shaped meshes in 3D

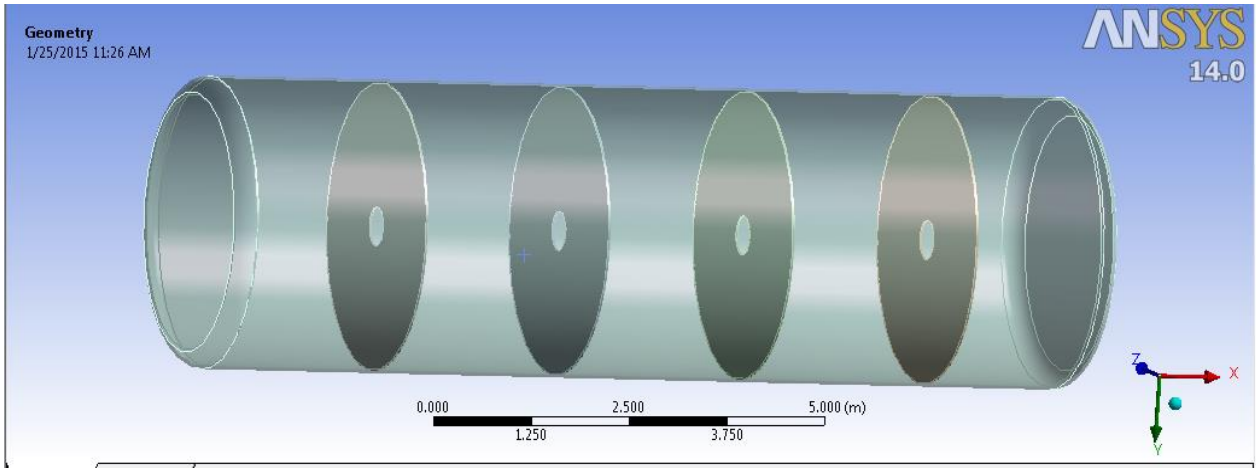


Fig. 3-5. Ansys modeling of Five-compartment fluid tank

3.4.3. Simulation Models

Simulation is expected to be done both by CFD and Simpack. Continuity equation used to describe the transport of conserved quantity. It also defines the conservation of mass. For 3-dimensional continuity equation for unsteady flow is as follow:

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

Where ‘ρ’ is the density, ‘t’ is time, and *u*, *v*, *w* are velocity components in *x*, *y*, *z* direction.

For incompressible and steady flow, continuity equation can be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

Turbulence Modeling: The model transport equation for k is derived from the exact equation, while the model transport equation for ε was obtained using physical reasoning and bears little resemblance to its mathematically exact counterpart. In the derivation of the k-ε model, it was assumed that the flow is fully turbulent, and the effects of molecular viscosity are negligible. The standard k-ε model is therefore valid only for fully turbulent flows. Although the form of the momentum equations remains the same, the viscosity term becomes an effective viscosity μ_{eff} and is determined by the sum of the molecular viscosity μ and a turbulent viscosity $\mu_{t.}$ The turbulent (or eddy) viscosity μ_t is computed by combining k and ε as follows:

$$\mu_t = \rho C_\mu \frac{K^2}{\varepsilon}$$

Where, $C_\mu$is an empirically derived proportionality constant, whose default value is 0.09 in fluent, ε is the turbulence dissipation rate (*which is 1.9 for Diesel*), *k is* turbulent kinetic energy (*which is 0.8 in this case*). This has been found to work fairly well for a wide range of wall-bounded and free shear flows. For the present simulation this k-ε turbulence model is chosen, as it is playing a vital part in solving problems with VOF technique even today [22], [appendix B].

The mass in the cylindrical tanker is, according to Bernoulli, handled as a *Body* which is accelerated by the force difference acting on the cross sections at both ends of the cylinder. The force difference depends on the total pressure difference of both reservoirs consisting of local pressure difference, height level difference and height level velocity difference. Decelerating effects are caused by drag and friction.

Simpack Modeling: The two bogie fluid wagon running both in the straight and the curved rail tracks have been modeled as shown in fig.3-6 bellow. The modeling has been done by Simpack 9.6 MBS package. The reference for dimensioning and appearance of this modeling is the Gn-70 existing fluid wagon.

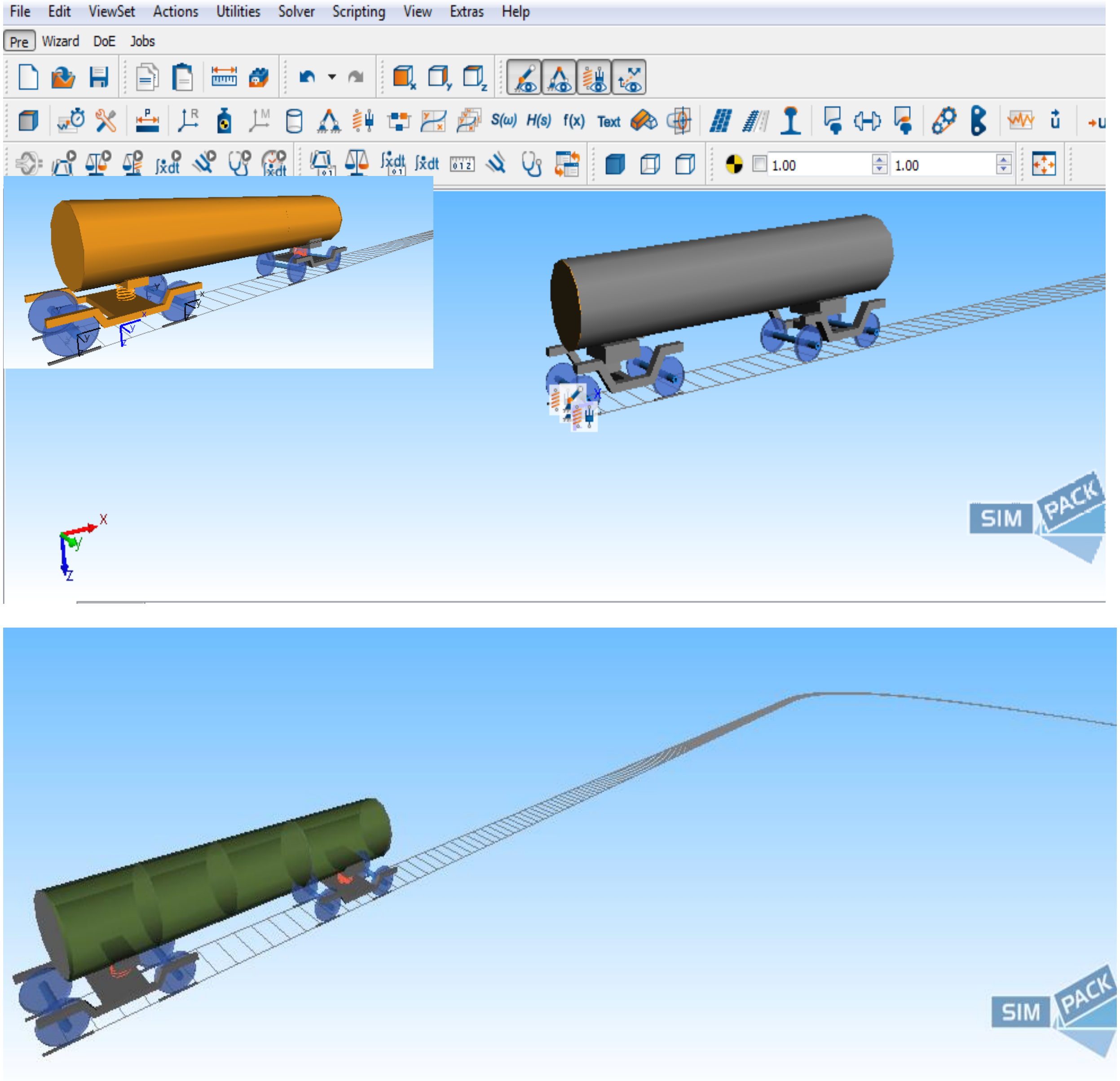


Fig. 3-6 SIMPACK modeling of Four-compartment fluid tank straight (up) & curved (down) track

3.5. Cost Comparison and Optimization

Comparing the costs of Locally Manufactured fuel Tank and Imported One:
Current international Price: The price of a fluid wagon tank ranges from 33,000 to 42,000 USD FOB (Dubai) = Approx. 660,000 – 840,000 Eth. Br

Locally mfg. price: mainly incorporates the costs of the material, consumable welding material, machining refering machine hour costs, man power cost, factory over-head, the profit margin and the Value Added Tax these can be calculated as follows:

A) **Material cost** = *(mass) x (price rate per kg)……………. (*)*

Mass of tanker = Density (ρ) x Volume (v_1)

$= (\rho_{carbon\ steel})\ x\ [(\pi)(D)(L)(t)]$

$= 7860\ kg/m^3\ x\ (\pi(2.6m)(12m)(0.011m))$

$= 8474.61$ kg ………………………………………………(a)

Mass of end covers & Baffle plates = 6(Density (ρ) x plate Volume (v_2)

$= 6\{(\rho_{carbon\ steel}))\ x\ [(w)(L)(t)]\}$

$= 6\{(7870\ kg/m3)\ x\ [(3m)(2.6m)(0.011m)]\}$ scrapes considered

$= 4046.33$ kg ……………………………………….....(b)

From (a) & (b), Total mass of tanker materials = 12520.94 kg.

From equation (*) The tanker material cost = *325,544.5 ETH. Br.*

(the price rate per kg. is about 26.00 Br.)

B) **Machining costs** = *(machine rate per hr.) x (machining hr.)…………………….(**)*

- *Machine rate per hr. is about 11.5 ETH.Br. effective as of month of January,2015 refering price set by local metal industries for bending combined with fusion welding machines*
- *Expected machining hr. calculated by considering machine settings, Idle and operation times; since it requires heavy duty workshop with precise locating as well as guiding fixture arrangement reasonably the machining hr. for welding and bending to construct the tanker expected approximately 48hrs.*

From (**) *the* Machining costs = *552.00 ETH. Br*

C) **Man power costs** = *(man power rate per hr.) x (operation hr.)……………………….(***)*

- *Man power rate refers to both the professional and the helper factory workers. For this study we can consider at least two senior-mechanics of gross salary 3300.00 Eth. Br. And five junior-operator helpers of gross salary 1800.00 Eth.Br.*
  Therefore, man power hourly rate will be:

$$\frac{[(2\times 3300.00)+(5\times 1800.00)]Br/month}{172\ working\ hr/month} = 90.70 \text{ Br. per hr.}$$

From (**) *the* Man power costs = *(90.70Br per hr.)(48 hrs.)* = *4,353.50 ETH. Br*

D) Consumable welding and painting material cost will be the costs of Oxy-Acetyline, anti-rust, synthetic paints and the Electrode costs that totally expected the value about 3002.00 Br. Considering 2 gallon synthetic paints of unit price 120 Br, 4 kg of anti-rust of unit price 95 Br, 6 china electrode of unit price 98 Br, and 6 bottles of Oxygen and Acetyline of unit price 299 Br.

From (A), (B), (C) and (D)

The total manufacturing cost of tanker is about 330,449.99 ETH. Br.

The total Production cost = $\left(cost_{mfg.}\right) + \left(Cost_{OH}\right)$ = $(cost_{mfg.})$ + [(10%) $(cost_{mfg.})$]

= *363,494.99 ETH. Br*.

The total selling cost before VAT = $\left(cost_{production}\right) + (profit\ margin)$

= $(cost_{production})$ + [(10%)$(cost_{production})$] = *399,844.49 ETH. Br*.

The Grand total selling cost including 15% VAT = $\left(cost_{selling}\right) + \left(cost_{VAT}\right)$

= $(cost_{selling})$ + [(15%)$(cost_{selling})$]

= *459,821.16 ETH. Br*.

The total cost of locally manufactured tanker is about = *459,821.16 ETH. Br*.

The total cost including 10% contingency for market fluctuation is about = *505,803.28 ETH. Br*.

Comment: the manufacturing price roughly shows that locally manufactured tanker worth a lower value that the difference is significant compared with the one which is imported from abroad delivered at ports of Dubai that it requires additional transporting costs so as to bring to the land. The cost break-down analysis has been done based on the standard manufacturing cost sheet from KCMPF which is attached in Appendix A.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. **Cost comparison**

As it has been stated on the cost analysis part in section 3.5, the price of locally manufactured fluid tank worth lower amount when compared with the cost of the similar tank which is import coming from abroad even before considering the transport cost of bringing the tank from the delivery port in Dubai. Thus it requires additional transport costs which we cannot neglect the amount of hard currency it requires.

We can also capable of manufacture the tank locally by reversing the technology then can save a significant amount of foreign currencies and time besides having the technology of product development in high tech mechanism process.

4.2. **CFD Results**

Mesh by FEA: A fluent model has been meshed by tetrahedron fine sized mesh of tanker and wagon on track looks like the following fig.

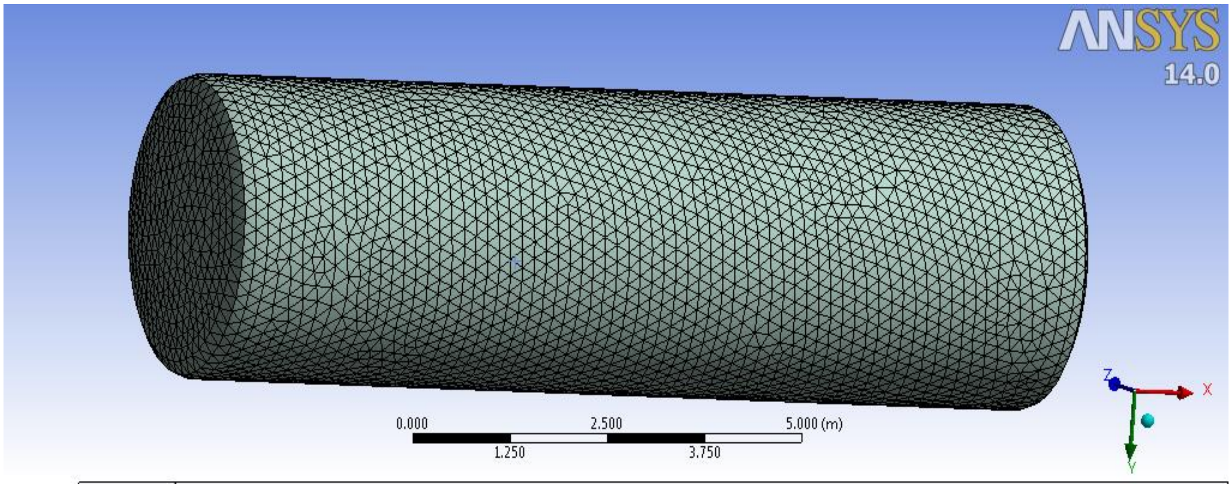


Fig. 4-1a. Fine sized fluent meshed fluid tank

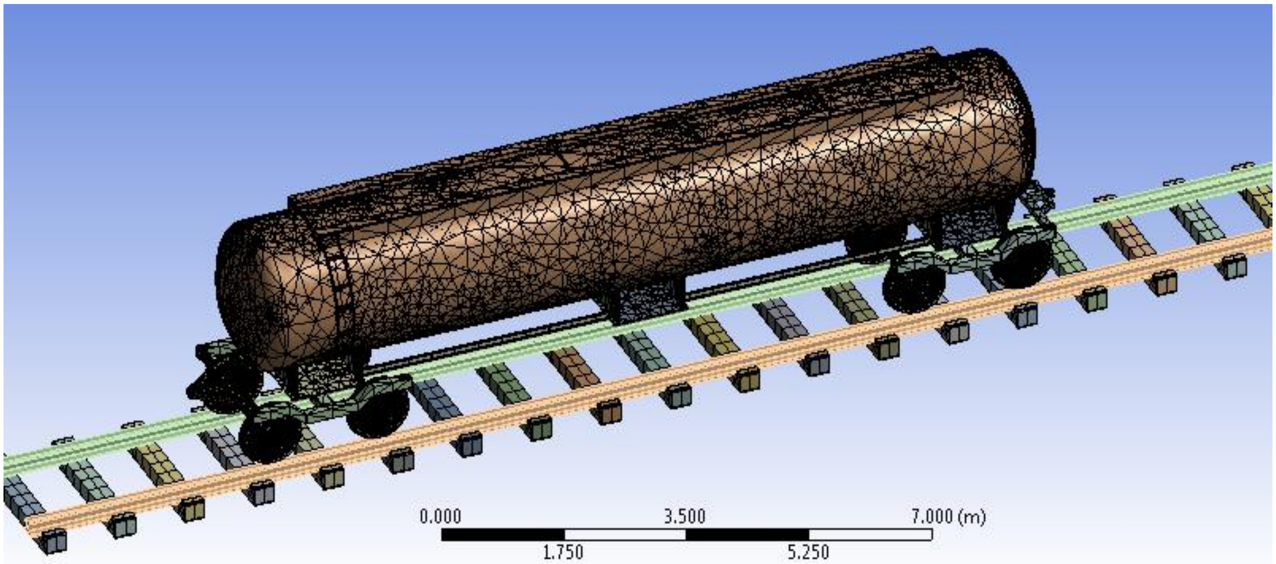
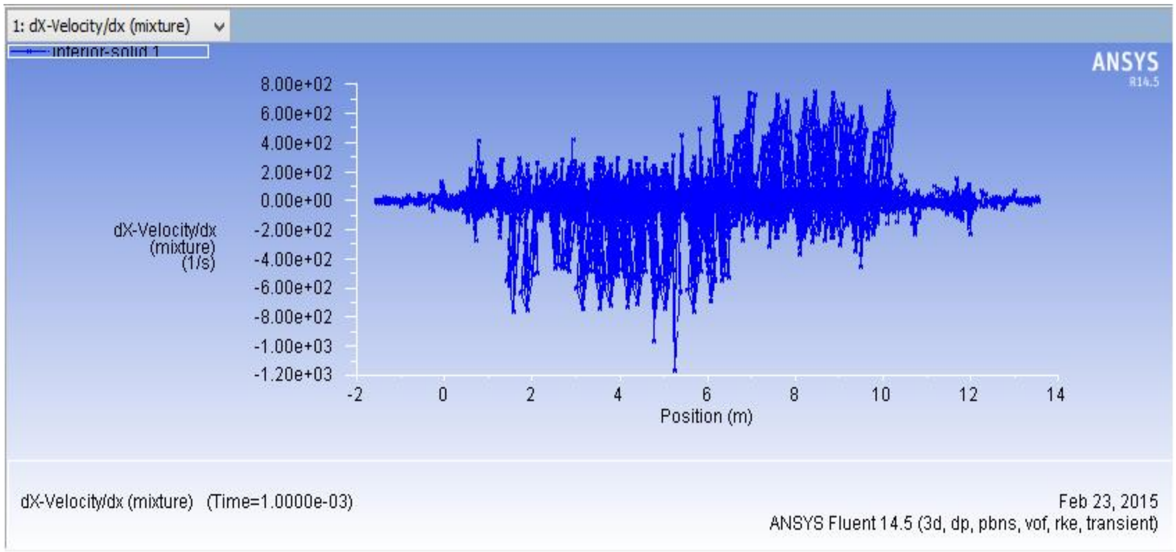


Fig. 4-1b. Fine sized fluent meshed fluid wagon on straight track [SW]

The following results are collected from Ansys Fluent CFD workbench. The primary and the secondary fluid material used in this study are air and Diesel with density 830kg/m^3 respectively.



dX-Velocity/dx (mixture) (Time=1.0000e-03)

Feb 23, 2015
ANSYS Fluent 14.5 (3d, dp, pbns, vof, rke, transient)

Fig. 4-2 velocity derivative graph along running direction

The above graph shows the velocity derivative of position, which is a fluid disturbance along position of a fluid particle

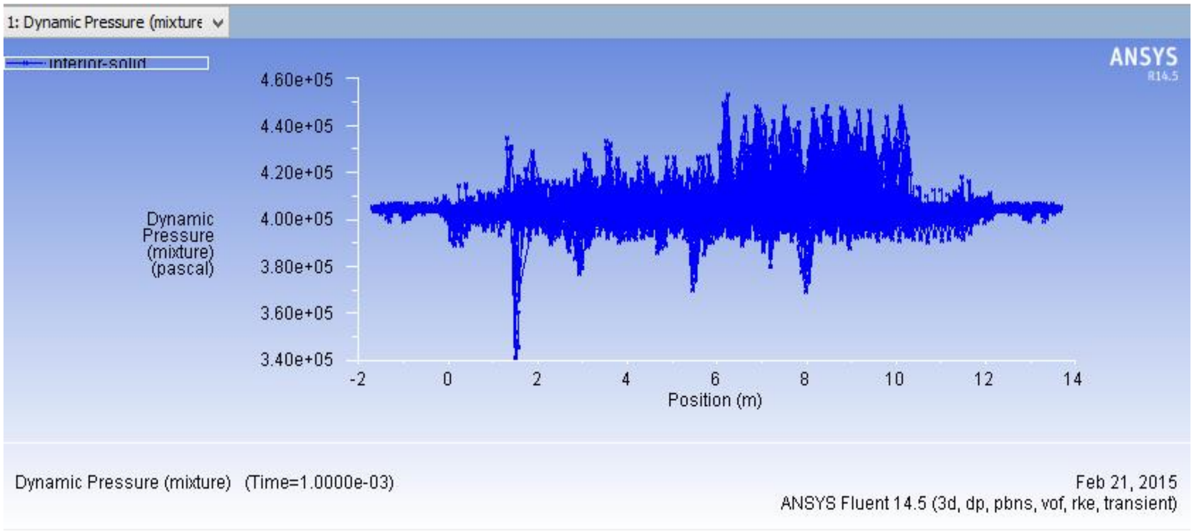


Fig. 4-3a. Dynamic pressure vs position at speed 33.33m/s

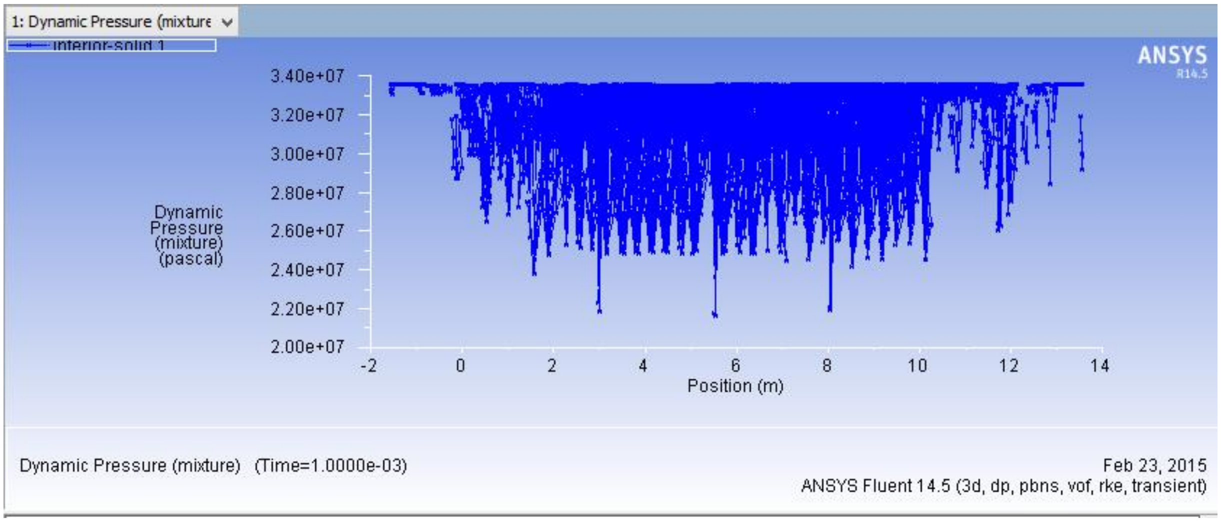


Fig. 4-3b. Dynamic pressure vs position at speed 20m/s

Fig 4-3a and fig 4-3b above, show that the dynamic pressure at higher speeds is higher and not uniformly distributed whereas the dynamic pressure at lower speed is relatively symmetrically distributed. The effect of such a fluid property will contribute increasing the accidents during running; but such type of disturbances happening inside the tanker may not be considered as the unbalancing initiator during running.

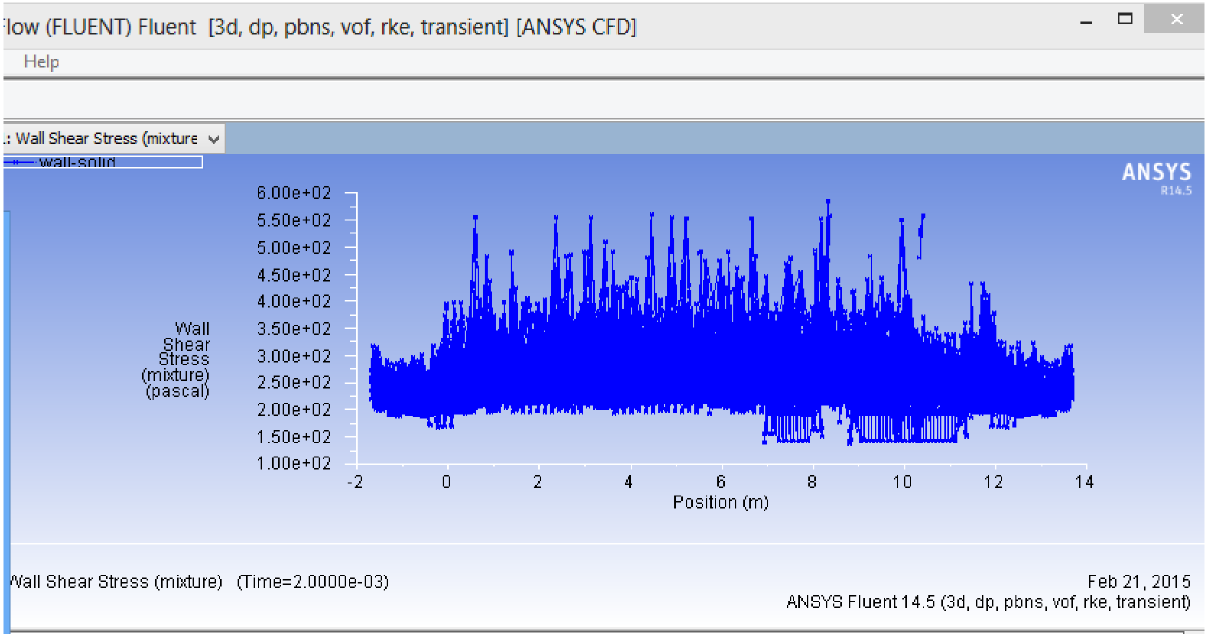


Fig. 4-4 x-direction wall shear stress

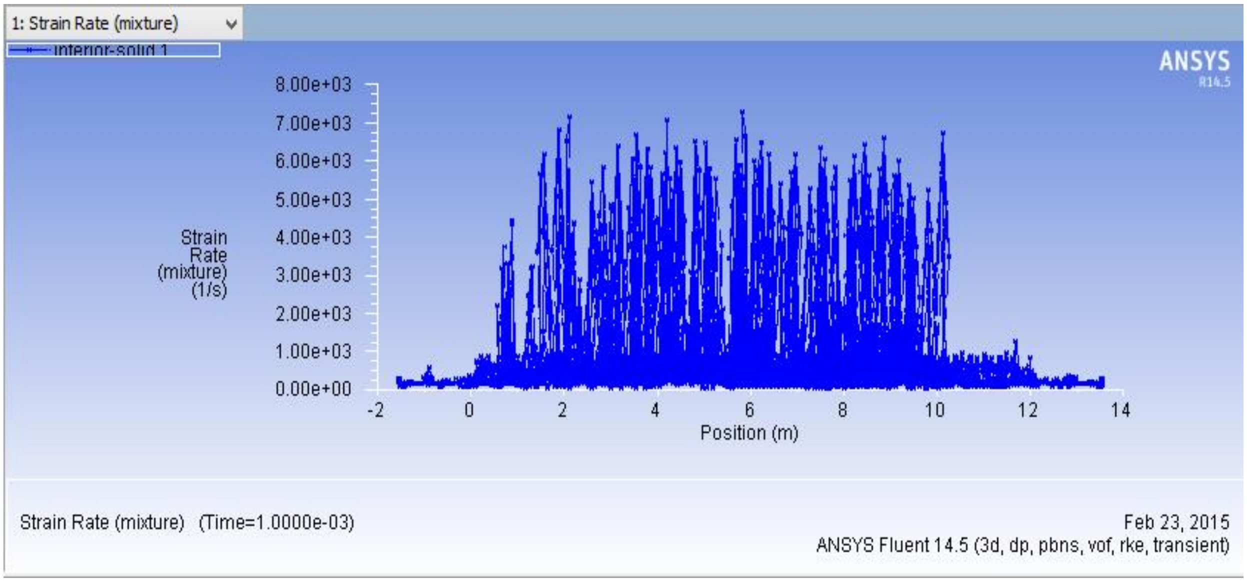


Fig. 4-5 Train rate diagram along running direction

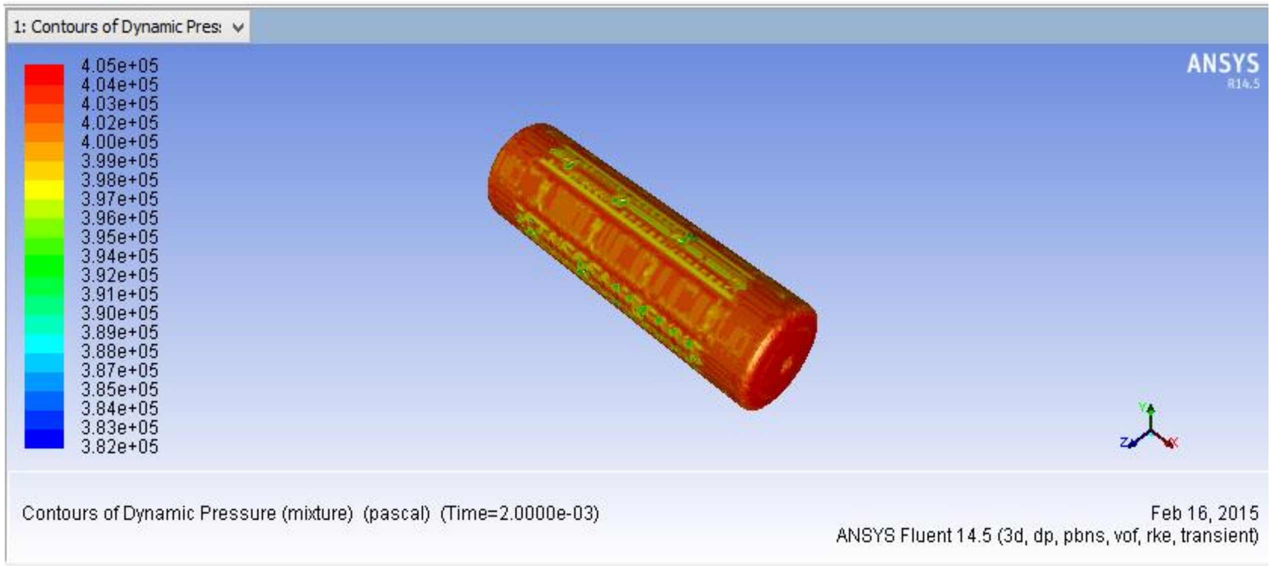


Fig. 4-6 Dynamic pressure distribution plot results

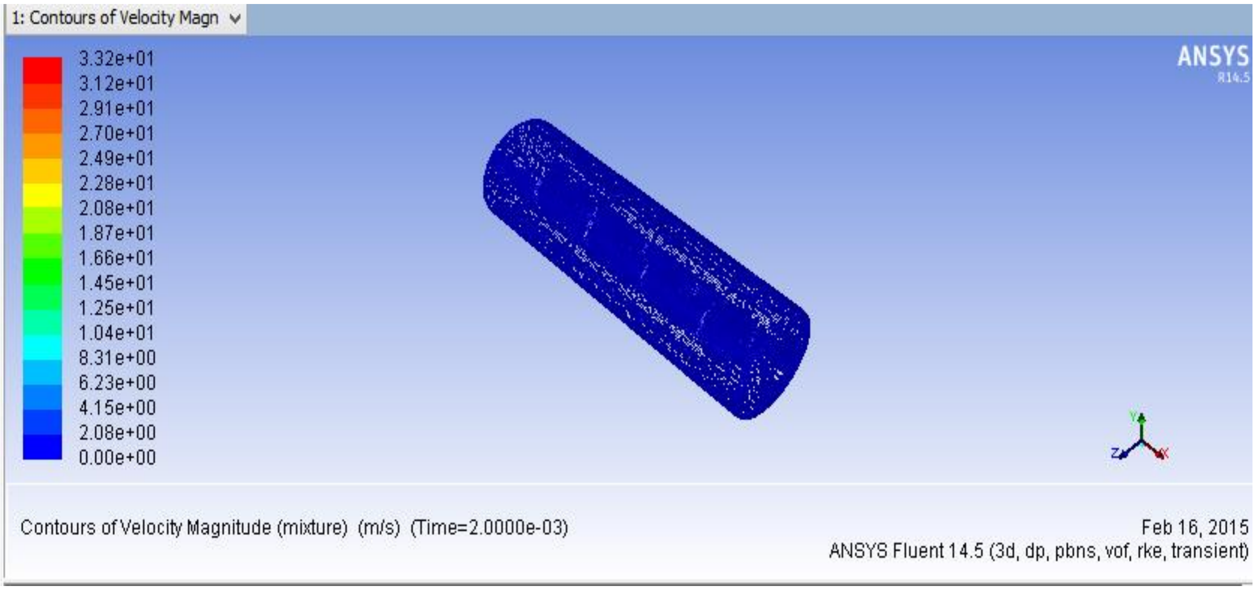


Fig. 4-7. Velocity Magnitude of fluid surface plot results

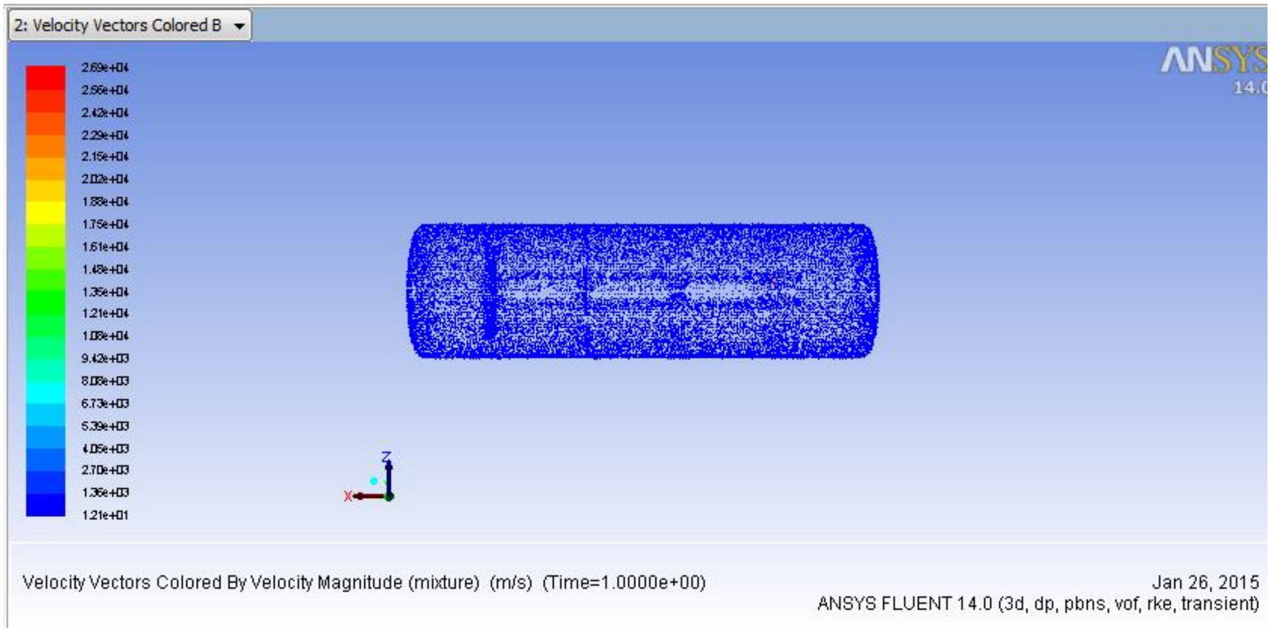


Fig. 4-8. Velocity vector distribution plot results

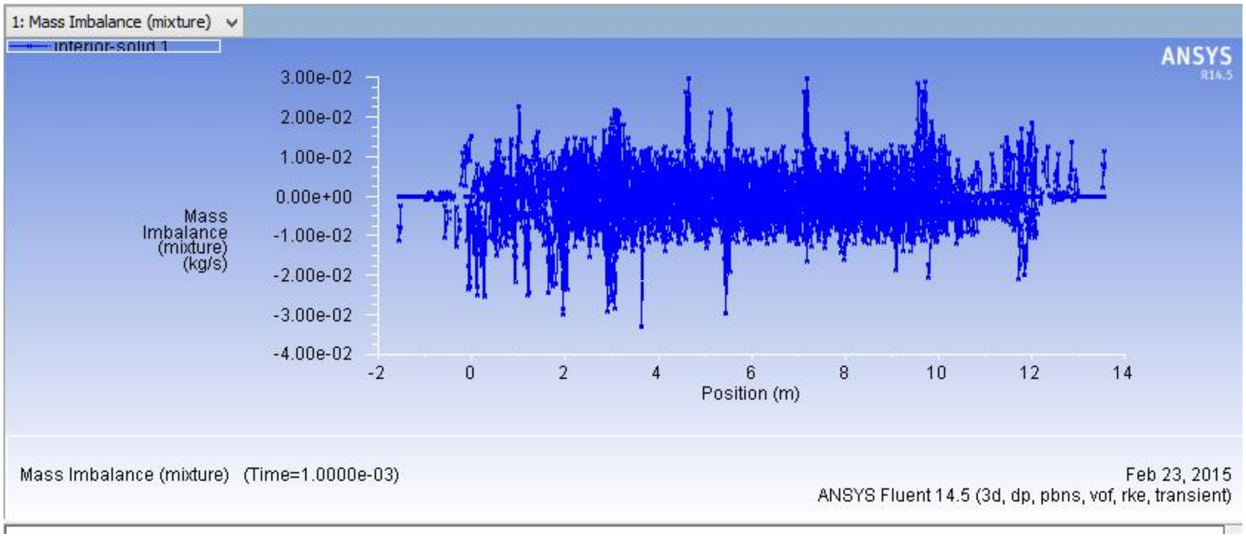


Fig. 4-9. Mass imbalance with respect to position

From above graph of fig. 4.9, the mass imbalance with respect to time along the position is occurred due to the property of the sloshing load which tends to shift location during wagon running could be observed. This effect probably leads the wagon not to be stable in conditions like turning and high speed longitudinal running of wagon holding partially filled loads.

4.3. SIMPACK Results

A tank wagon modeled by Simpack as shown in fig 3-6 has been simulated and the corresponding Time integration results have been collected for 320m total running length of the rail track. from which about 200 meter length is on curved track with critical curvature radius of 145m. with track transition length of 3m. The forces as well as the acceleration diagram results during running of wagon for three different fluid Fill-levels have been collected accordingly as follows:

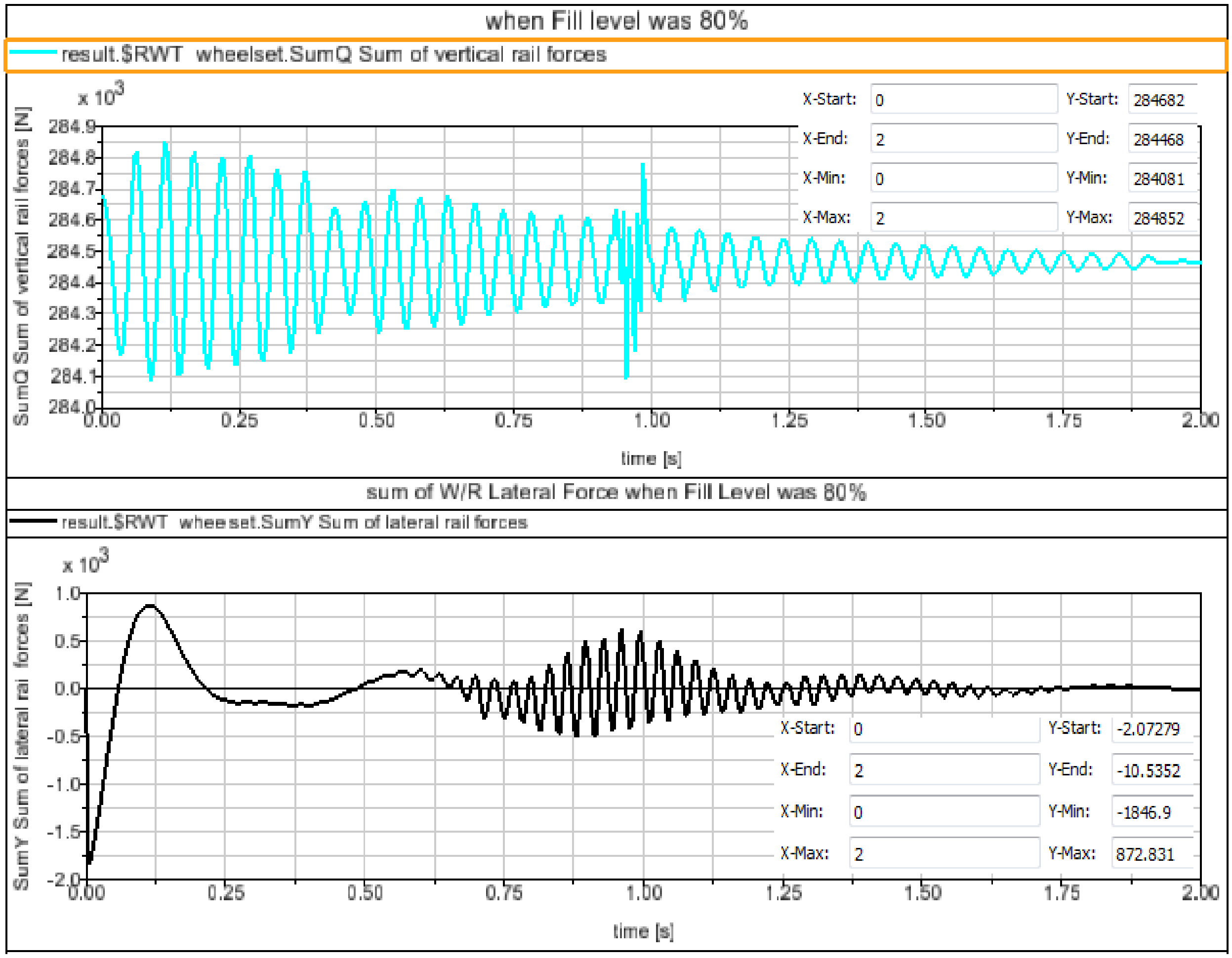
4.3.1. Results When Speed was 25 m/s [90 km/hr]

The Critical curve Radius of the track specified on specification of the wagon is about 145m. The force and acceleration simulation result graphs from Simpack post are shown below. The results are taken from Simpack post workbench regarding the load applied on the wagon proportionally given as of the load of the fluids fill level.

4.3.1.1. Force Result Diagrams

a) When the Fill-Level was 80%

The load feeding screen will be given with the value of load which is proportional with the capacity of the wagon. In this case, 80% of the wagon load capacity is about 56tons since the Gn-70 wagon is designed to hold a total load of 70tons. Then the wagon preload calculation allowed simulating with 25m/s speed and the time-historic online along with offline results have been saved to be stored on the simpack post-processing result display window.



X-Start: 0
X-End: 2
X-Min: 0
X-Max: 2
Y-Start: 284682
Y-End: 284468
Y-Min: 284081
Y-Max: 284852

X-Start: 0
X-End: 2
X-Min: 0
X-Max: 2
Y-Start: -2.07279
Y-End: -10.5352
Y-Min: -1846.9
Y-Max: 872.831

Fig. 4-10. Total Rail/wheel-set forces [Vertical (above) and Lateral (below) forces] - 80% loaded

The above graphs in fig. 4.10 clarify the maximum force amplitudes of vertical and lateral forces between the wheel-set and the rail at fill level of 80%. The force propagation signal in the graph shows the motion disturbance is not uniform due to the track is combination of straight along with curved rail.

b) When the Fill-Level was 65%

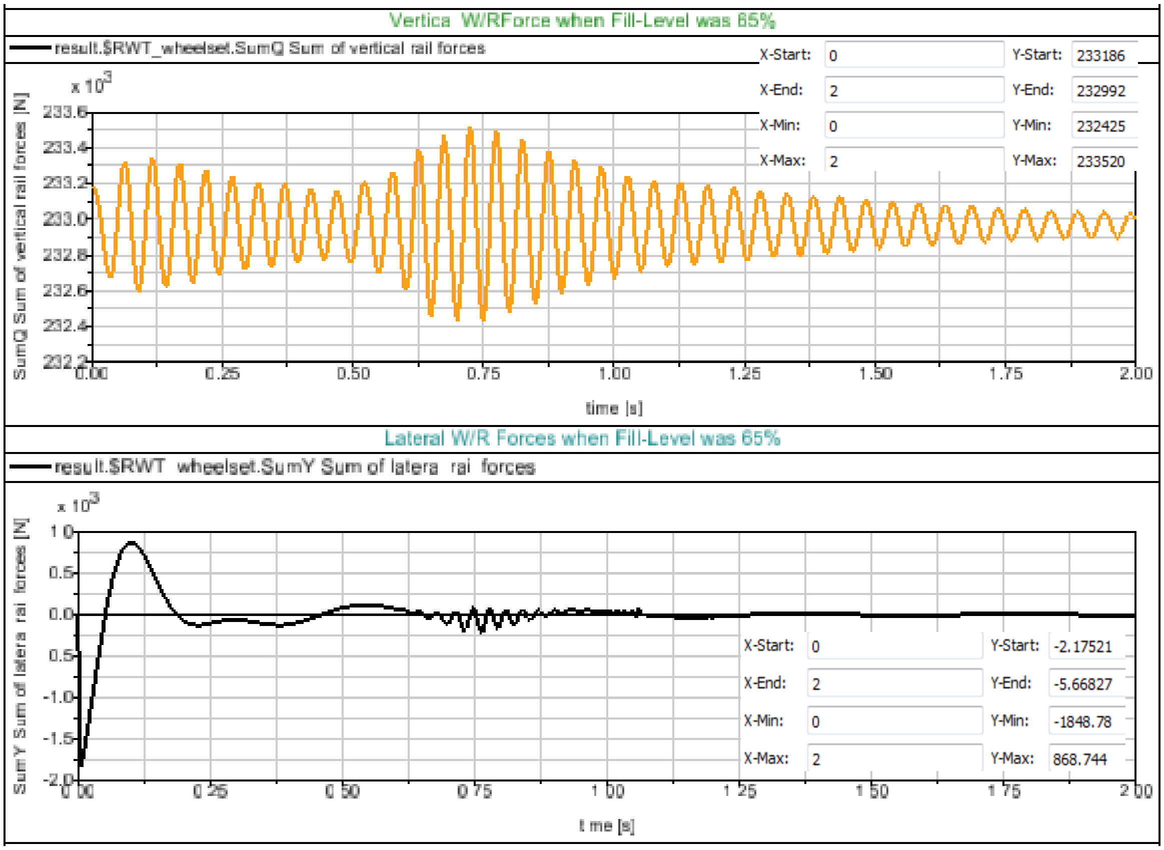
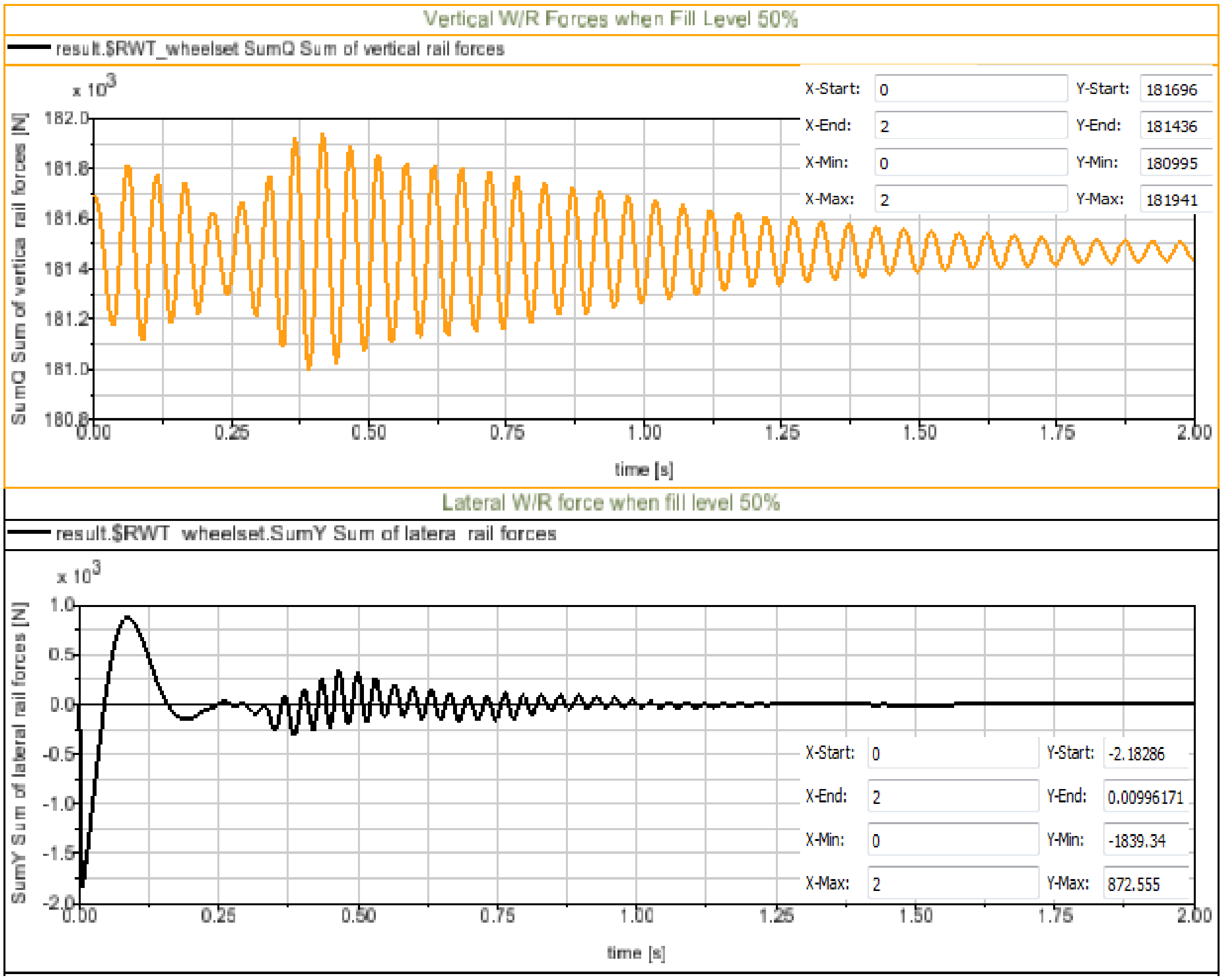


Fig. 4-11. Total Rail/wheel-set forces [Vertical (above) and Lateral (below) forces] - 65% loaded

In the above graphs of fig. 4.11, it has been shown the graph of amplitudes of both vertical and lateral forces between the wheel-set and the rail at fill level of 65%. The force propagation at 90km/hr speed is properly shown in forward motion but amplitude varies in magnitude due to the rail track is not constant but it is a combination of straight with curvatures.

c) When the Fill-Level was 50%

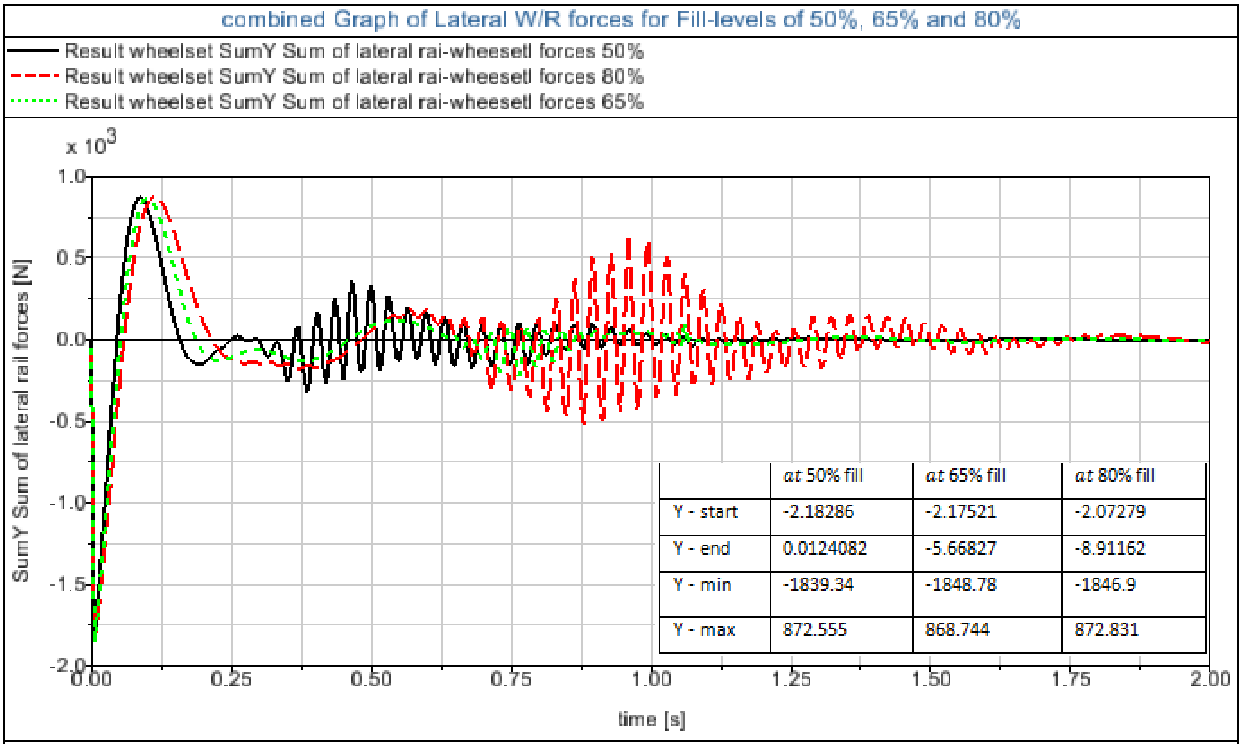


X-Start: 0
X-End: 2
X-Min: 0
X-Max: 2
Y-Start: 181696
Y-End: 181436
Y-Min: 180995
Y-Max: 181941

X-Start: 0
X-End: 2
X-Min: 0
X-Max: 2
Y-Start: -2.18286
Y-End: 0.00996171
Y-Min: -1839.34
Y-Max: 872.555

Fig. 4-12. Total Rail/wheel-set forces [Vertical (above) and Lateral (below) forces] - 50% loaded

The graphs in fig. 4.12, show the actual running wheel set force amplitudes of both vertical and lateral forces between the wheel-set and the rail at fill level of 50%,



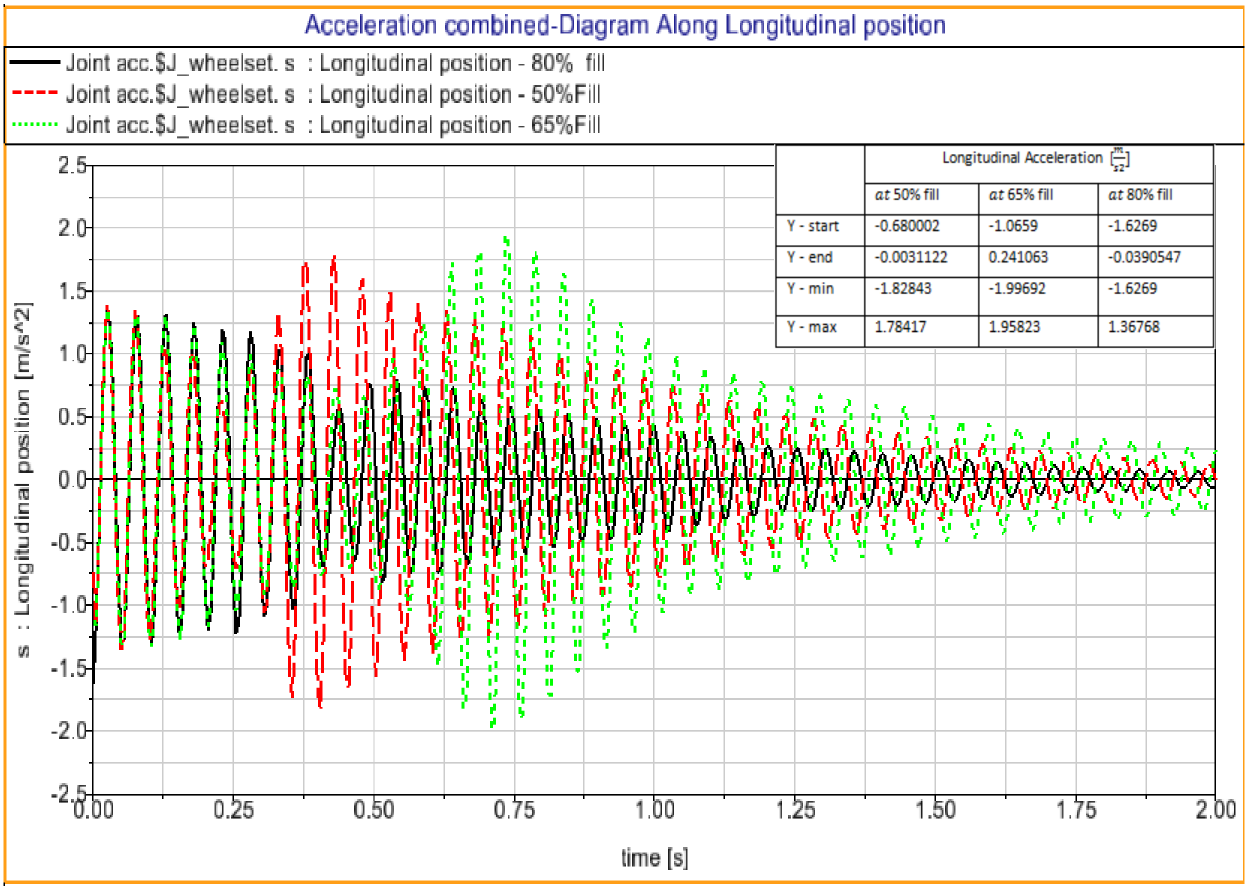
	at 50% fill	*at* 65% fill	*at* 80% fill
Y - start	-2.18286	-2.17521	-2.07279
Y - end	0.0124082	-5.66827	-8.91162
Y - min	-1839.34	-1848.78	-1846.9
Y - max	872.555	868.744	872.831

Fig. 4-13. Combined graph of Total Rail/wheel-set Lateral forces [for 80%, 65% and 50% loaded wagon]

In the above graphs fig. 4.13, the combined graph of amplitude results of the lateral forces between the wheel-set and the rail for fill levels of 50%, 65% and 80% is shown. The lateral effect of the loaded fluid is higher at fill levels of 50% and 80% while the effect is somewhat smaller on fill levels of 65%. This can be occurred because the balancing location of load cg with respect to the cross section dimension of the tanker that load shift is directly proportional with cg position. This shows that the cg location is contributing the load shift effect during curving and may result to rollover of the wagon.

On the other hand, the vertical force is directly proportional with the loaded fluid volume irrespective of the location of cg.

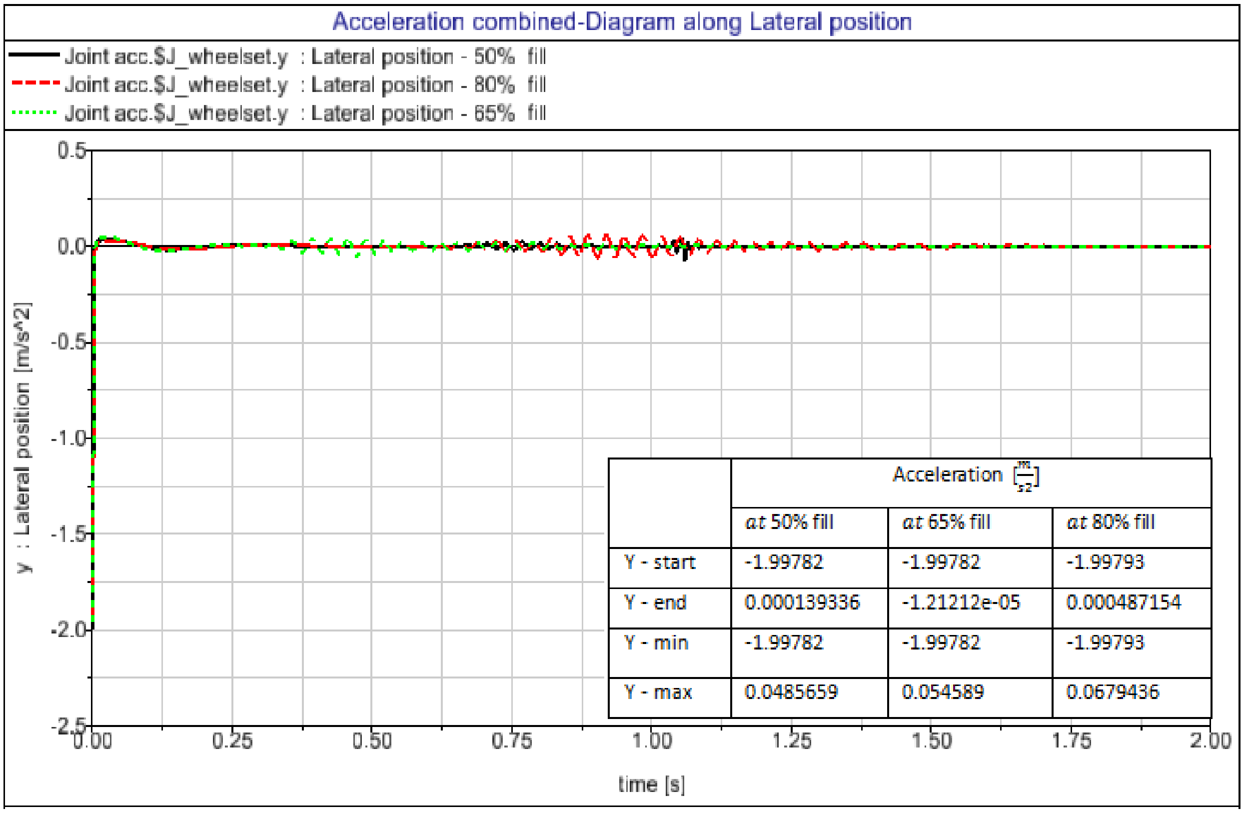
4.3.1.2. **Acceleration** Result **Diagrams**



	Longitudinal Acceleration $[\frac{m}{s2}]$		
	at 50% fill	*at* 65% fill	*at* 80% fill
Y - start	-0.680002	-1.0659	-1.6269
Y - end	-0.0031122	0.241063	-0.0390547
Y - min	-1.82843	-1.99692	-1.6269
Y - max	1.78417	1.95823	1.36768

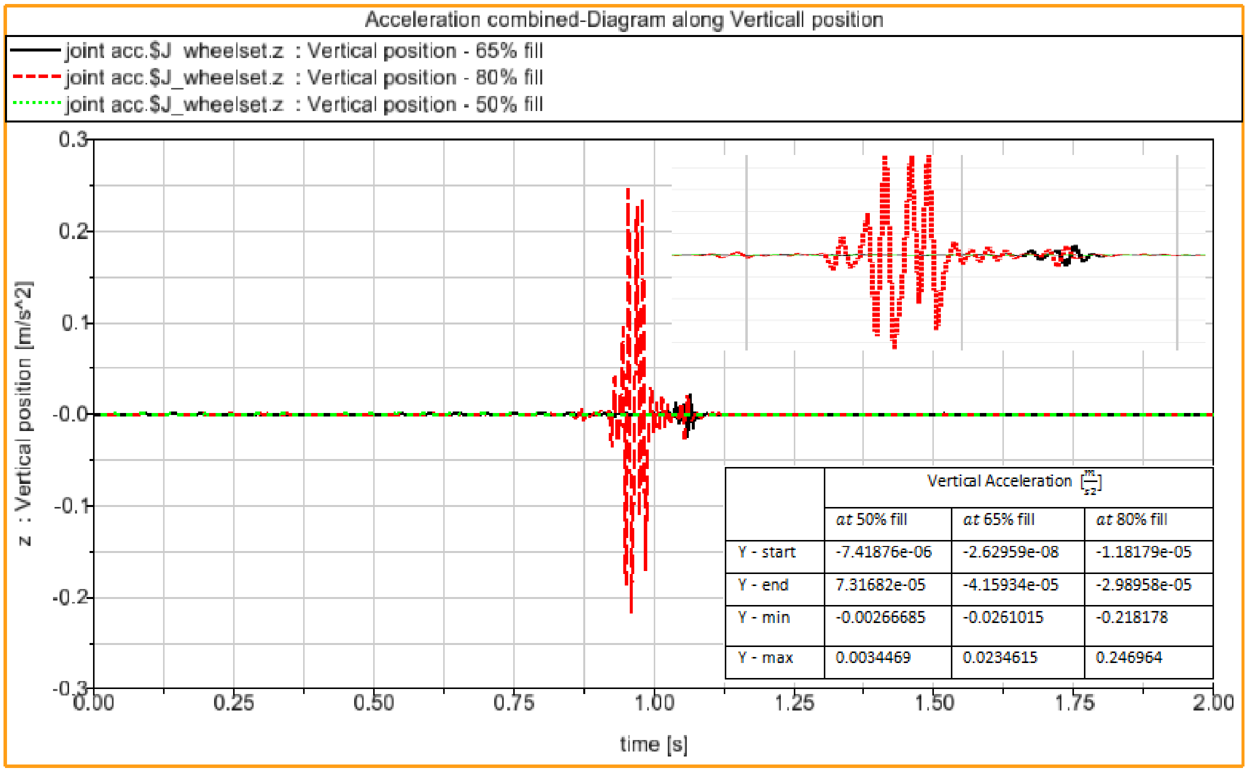
Fig. 4-14. Wheel-set Acceleration of wagon along longitudinal position [for 80%, 65% and 50% load]

Fig 4-14 shows that the combined graph of amplitude results of the longitudinal position accelerations of the wheel-set for fill levels of 50%, 65% and 80%. We can observe that the forward acceleration is not directly dependent on the fill level but simultaneously it depends on the cg location of the load. We can clearly observe from the above diagram that the peak acceleration of on fill levels of 65% is greater than the other two fill levels. This can be happened due to the center of mass is more unstable on 65% loading than the other two fill-levels. This implies that the fill level is contributing the wagon control in motion due to affecting the fluid sloshing conditions and results the wagon turnover and longer braking distance especially during high running speeds.



	Acceleration $[\frac{m}{s2}]$		
	at 50% fill	*at* 65% fill	*at* 80% fill
Y - start	-1.99782	-1.99782	-1.99793
Y - end	0.000139336	-1.21212e-05	0.000487154
Y - min	-1.99782	-1.99782	-1.99793
Y - max	0.0485659	0.054589	0.0679436

Fig. 4-15. Wheel-set Acceleration of wagon along lateral position [for 80%, 65% and 50% load]



	Vertical Acceleration $[\frac{m}{s2}]$		
	at 50% fill	*at* 65% fill	*at* 80% fill
Y - start	-7.41876e-06	-2.62959e-08	-1.18179e-05
Y - end	7.31682e-05	-4.15934e-05	-2.98958e-05
Y - min	-0.00266685	-0.0261015	-0.218178
Y - max	0.0034469	0.0234615	0.246964

Fig. 4-16. Wheel-set Acceleration of wagon along vertical position [for 80%, 65% and 50% load]

The above two figures of Fig 4-15 and Fig 4-16 show that the combined graph of result magnitudes of the lateral and the vertical position accelerations of the wheel-set for fill levels of 50%, 65% and 80%. We can clearly see that both the lateral as well as the vertical accelerations is directly dependent on the fill level of the wagon load. That is the higher the load of the wagon, the higher the lateral and the vertical accelerations. This implies that whenever the fill level increases the location of the cg will be higher from the stable location that it contributes higher to the rollover of the wagon during turning on curves in lateral motions.

4.3.2. Results When Speed Was 33.33 m/S [120 km/hr.]

Here the Critical curve Radius of the track is not enough to let the wagon run with this speed rather the curve should be at least 200m. the force and acceleration simulation graphs from Simpack results are shown below.

4.3.2.1. Force Result **Diagrams**

a) When the Fill-Level was 80%

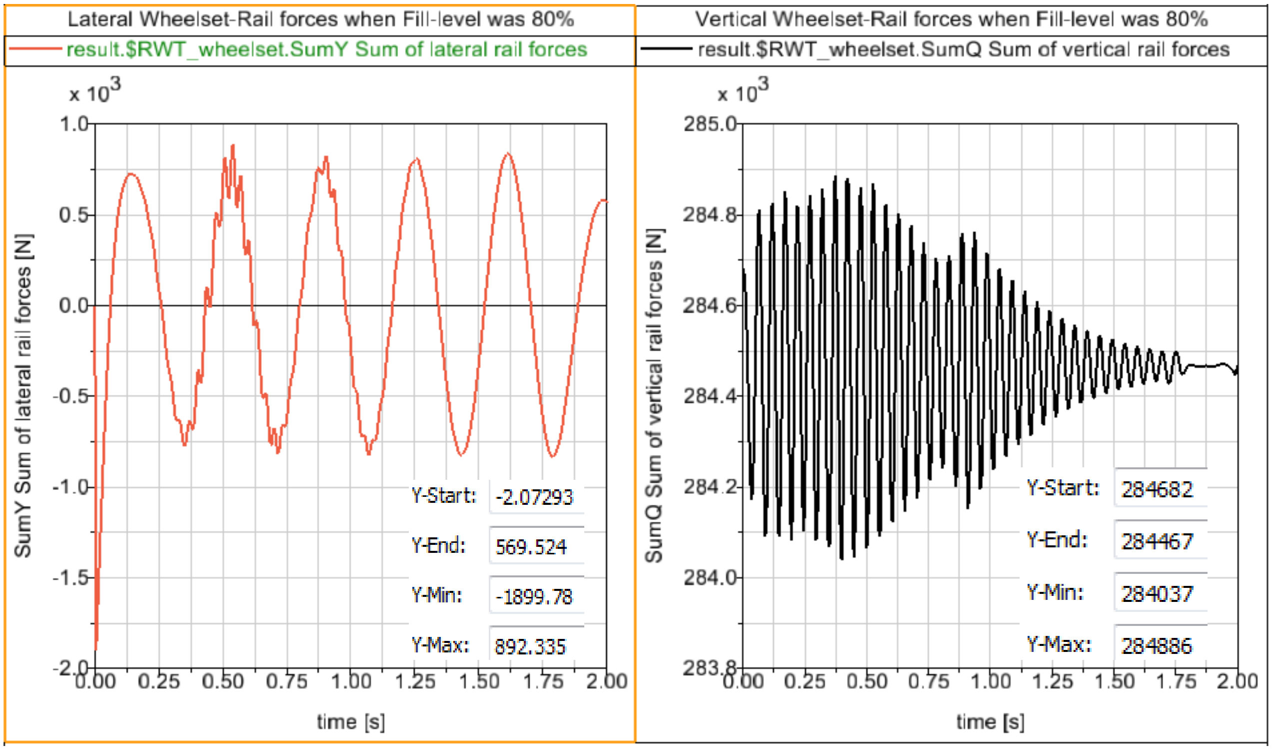


Fig. 4-17. Total Rail/wheel-set forces [Lateral (left) and Vertical (right) forces] - 80% loaded

b) When the Fill-Level was 65%

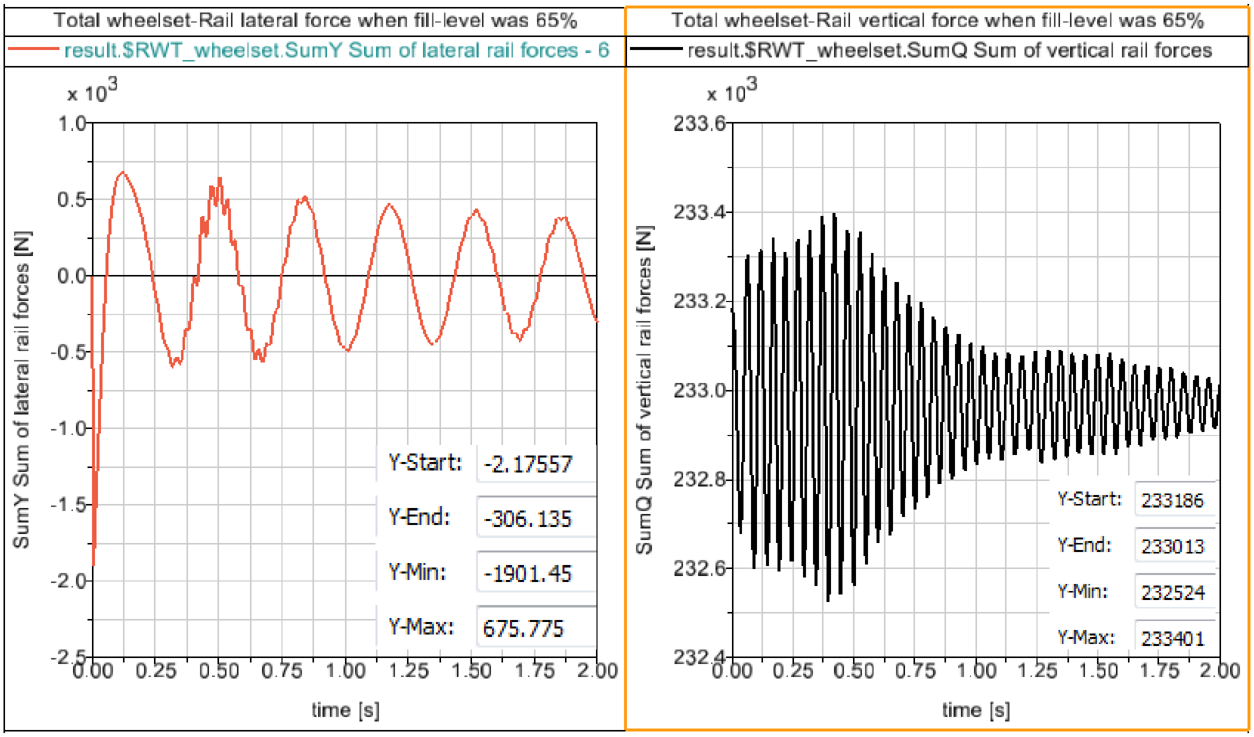


Fig. 4-18. Total Rail/wheel-set forces [Lateral (left) and Vertical (right) forces] - 65% loaded

c) When the Fill-Level was 50%

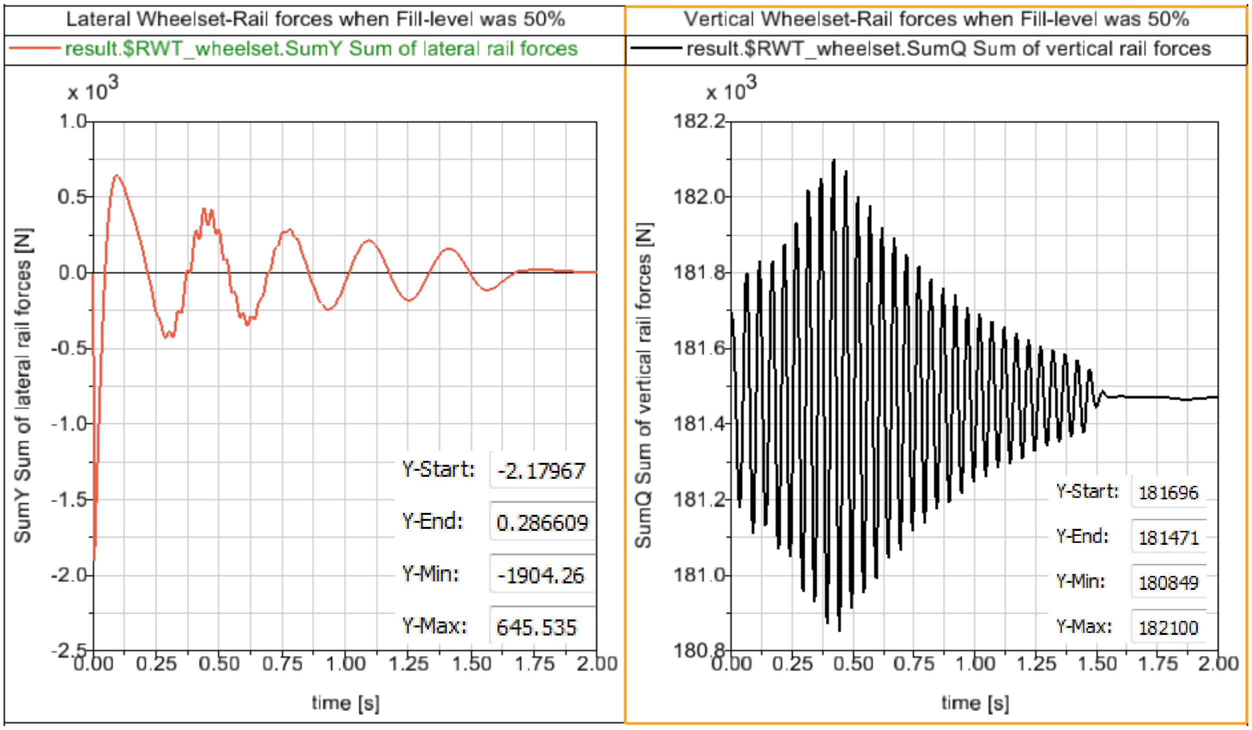
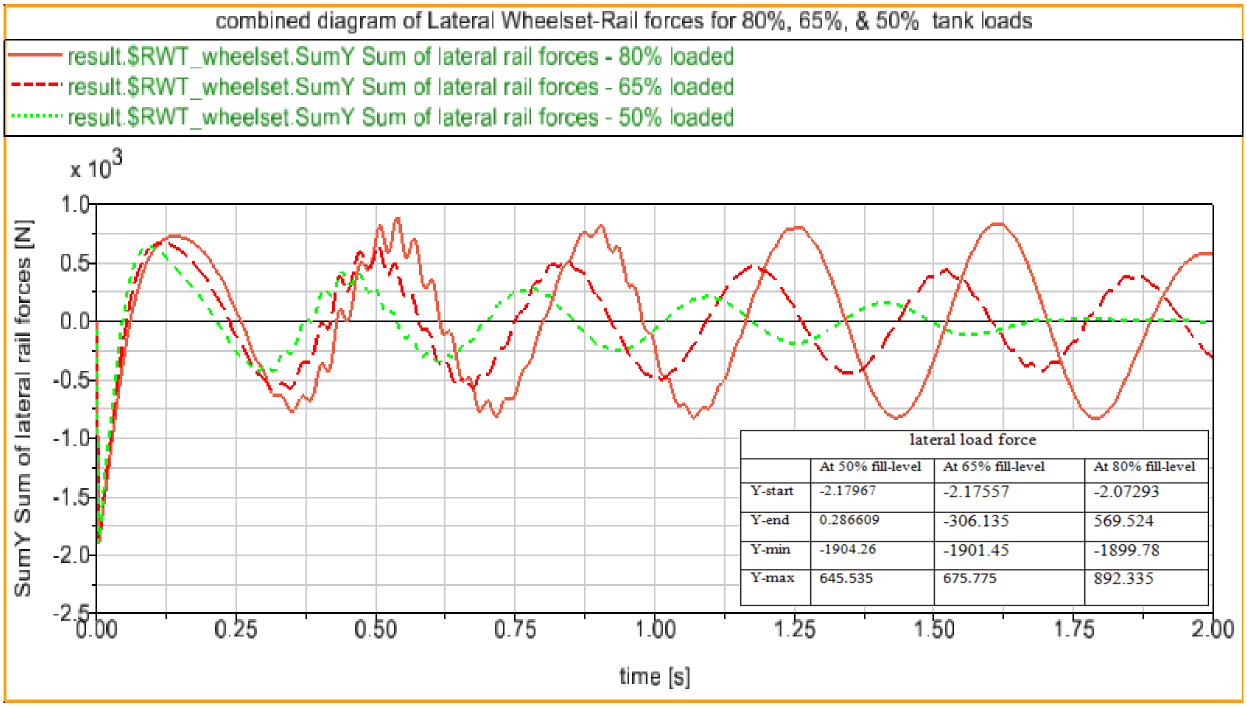


Fig. 4-19. Total Rail/wheel-set forces [Lateral (left) and Vertical (right) forces] - 50% loaded

The above graphs of Fig 4-17, Fig 4-18 and Fig 4-19 show that the lateral and the vertical forces for tested three points fill levels of 50%, 65% and 80% are directly proportional with loads inside the tank. That is the higher the load of the wagon, the higher the lateral and the vertical forces between the wheel-set and the rails.

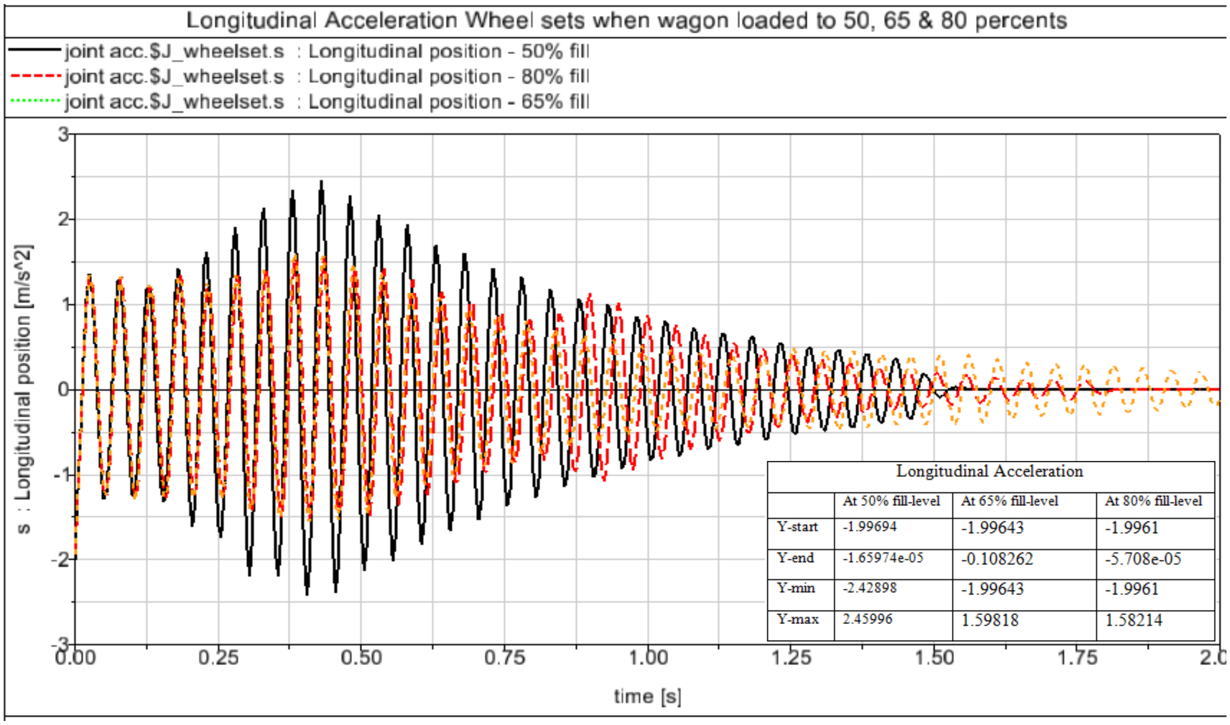


lateral load force			
	At 50% fill-level	At 65% fill-level	At 80% fill-level
Y-start	-2.17967	-2.17557	-2.07293
Y-end	0.286609	-306.135	569.524
Y-min	-1904.26	-1901.45	-1899.78
Y-max	645.535	675.775	892.335

Fig. 4-20. Combined graph of Total Rail/wheel-set Lateral forces [for 80%, 65% and 50% loaded wagon]

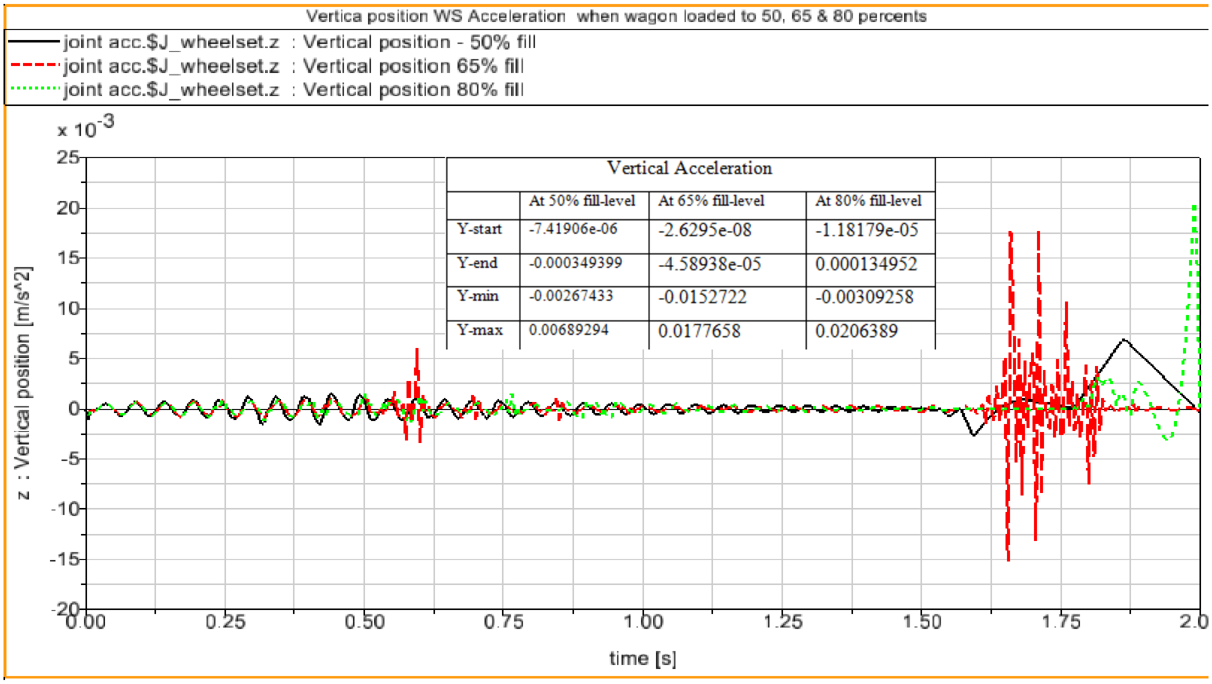
The above graph of fig. 4.20 clarifies the combined graph of amplitude results of the lateral forces between the wheel-set and the rail for fill levels of 50%, 65% and 80%. We can observe that the lateral effect of the loaded fluid is higher at higher fill levels. This is due to the relatively higher curvature radius relatively with curvatures critically allowed for speed of 90km/hr. This shows that the cg location is contributing the load shift effect during curving with higher load and may result to rollover of the wagon.

4.3.2.2. **Acceleration** Results **Diagram**



Longitudinal Acceleration			
	At 50% fill-level	At 65% fill-level	At 80% fill-level
Y-start	-1.99694	-1.99643	-1.9961
Y-end	-1.65974e-05	-0.108262	-5.708e-05
Y-min	-2.42898	-1.99643	-1.9961
Y-max	2.45996	1.59818	1.58214

Fig. 4-21. Combined graph of W/S Acceleration of wagon in longitudinal position [for 80%, 65% and 50% load]



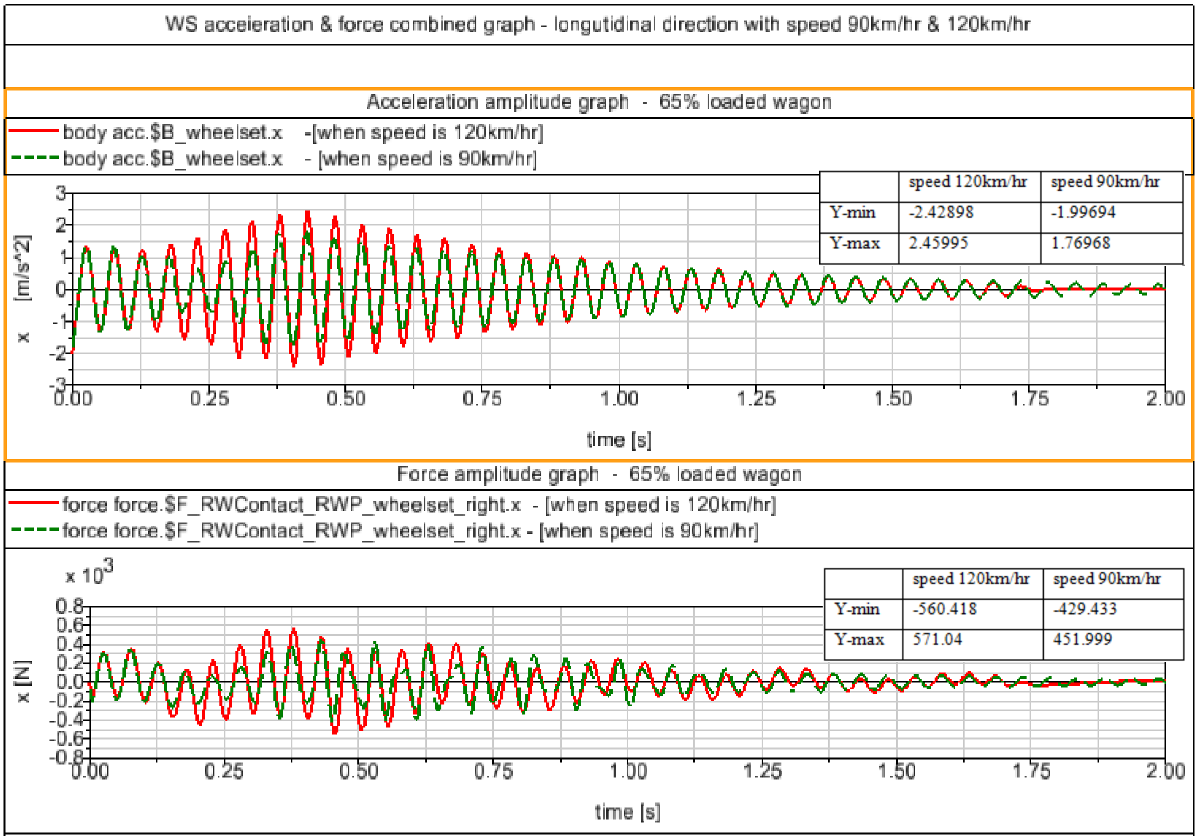
Vertical Acceleration			
	At 50% fill-level	At 65% fill-level	At 80% fill-level
Y-start	-7.41906e-06	-2.6295e-08	-1.18179e-05
Y-end	-0.000349399	-4.58938e-05	0.000134952
Y-min	-0.00267433	-0.0152722	-0.00309258
Y-max	0.00689294	0.0177658	0.0206389

Fig. 4-22. Combined graph of W/S Acceleration of wagon in vertical position [for 80%, 65% and 50% load]

The above two graphs of fig. 4.21 and Fig 4-22 show that the combined graph of the longitudinal position acceleration amplitude results are inversely related with the wagon fill level whereas the vertical position acceleration amplitude results for the 50%, 65% and 80% fill levels are directly proportional with loading value. This implies that it is better to fill the tanker to higher level in longitudinal running that will reduce the sloshing effect that tends to unstable the wagon in motion.

4.3.3. Acceleration and Force Results

The acceleration and the force along the longitudinal direction has been simulated and the corresponding combined results of Acceleration as well as forces of 65% loaded wagon when it runs with two different speeds has been collected as shown in fig. 4-23 below.



	speed 120km/hr	speed 90km/hr
Y-min	-2.42898	-1.99694
Y-max	2.45995	1.76968

	speed 120km/hr	speed 90km/hr
Y-min	-560.418	-429.433
Y-max	571.04	451.999

Fig. 4-23. Combined graph of Longitudinal Accelerations & Forces of **a** W/S [wagon loaded to 65%]

From the above graphs, someone can clearly observe that the force as well as the acceleration amplitude values becoming higher whenever the speed of the wagon increases that probably happen during running through the track transition towards curvatures. This indicates that the force magnitude will be safe and minimum when the wagon passes by reducing the running speed.

CHAPTER FIVE

CONCLUSION, RECOMMENDATION and FUTURE WORKS

5.1. Conclusion

The sloshing force and moment caused by the fluid instability in the partially filled cylindrical fuel tank subjected to longitudinal and combined lateral/longitudinal accelerations are investigated. And the simulation of the partially filled fluid wagon is carried out using the MBS packages of ANSYS FLUENT v14.5 and SIMPACK 9.6. Thus the following conclusions are made from the results:

- The sloshing force fluctuations and the corresponding accelerations are increasing correspondingly when the speed increases.
- The motion of the wagon is unstable due to the sloshing effect of the fluid
- Fluid transportation is not as easily controllable as solid loads since it tends to shift the center of load concentration during braking and accelerating
- Local wagon manufacturing cost of wagon has an advantage in technology adaptation along with saving of commissioning time and money.
- The speed of the fluid wagons should be lower enough not greater than 90km/hr. in critical curvature radius of 145m to pass safely without rollover.
- The motion with increasing velocity will face with higher dynamic pressure that possibly increase the buffering compression inside the tank if the relief spacing is not sufficient….etc

5.2. Recommendations

Whenever the fluid wagons tries to pass through the curvature, the passing speed must be reduced to safer value that cannot lead the wagon to rollover especially when the curve is small. The longitudinal running in higher speeds possibly affected by the unstable loads especially during braking; thus, it is recommended to use good damping draft-gears between the couplings in long freight transportation to reduce the load propagation towards the front vehicle in sudden braking. It is better to manufacture the fluid wagon locally instead of importing it from abroad to save the hard currency along with the advantage of technology adaptation.

5.3. Future Works

The present study is an attempt to evaluate the effect of sloshing loads being transported by a running wagon emphasizing the case of different fill-levels of fluid loads inside a cylindrical tank.

The following future works are being suggested to be considered in thesis works of mechanical railway students who are interested in Freight motion dynamics:

- Studying the case of transporting of Granules – motion characteristics and effects of load shifting behavior in bulk granule transportation
- 3D simulation of granular materials and fluids using PASIMODO coupled with Simpack
- Study the effects of cross-sectional shapes of fluid wagons
- Dynamic analysis of fluids running in an inclined track – cases of up moving and / or down moving through inclined track, etc
- Study the baffling arrangements in unstable load transportation like fluids and micronized powders

*****

6. Reference

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[2] Egidio Di Gialleonardo , Antonio Premoli , Stefano Gallazzi & Stefano Bruni (2013) "Sloshing effects and running safety in railway freight vehicles, Vehicle System Dynamics": International Journal of Vehicle Mechanics and Mobility, 51:10, 1640-1654

[3] K.M.Tehrani, S.Rakheja, I.Stiharu. "Three-dimensional analysis of transient slosh within a partly-filled tank equipped with baffles". Journal of vehicle system dynamics, vol. 45, pp.525-548.

[4] ANSYS-FLUENT 13.0 theory Guide, User guide, ANSYS Inc.

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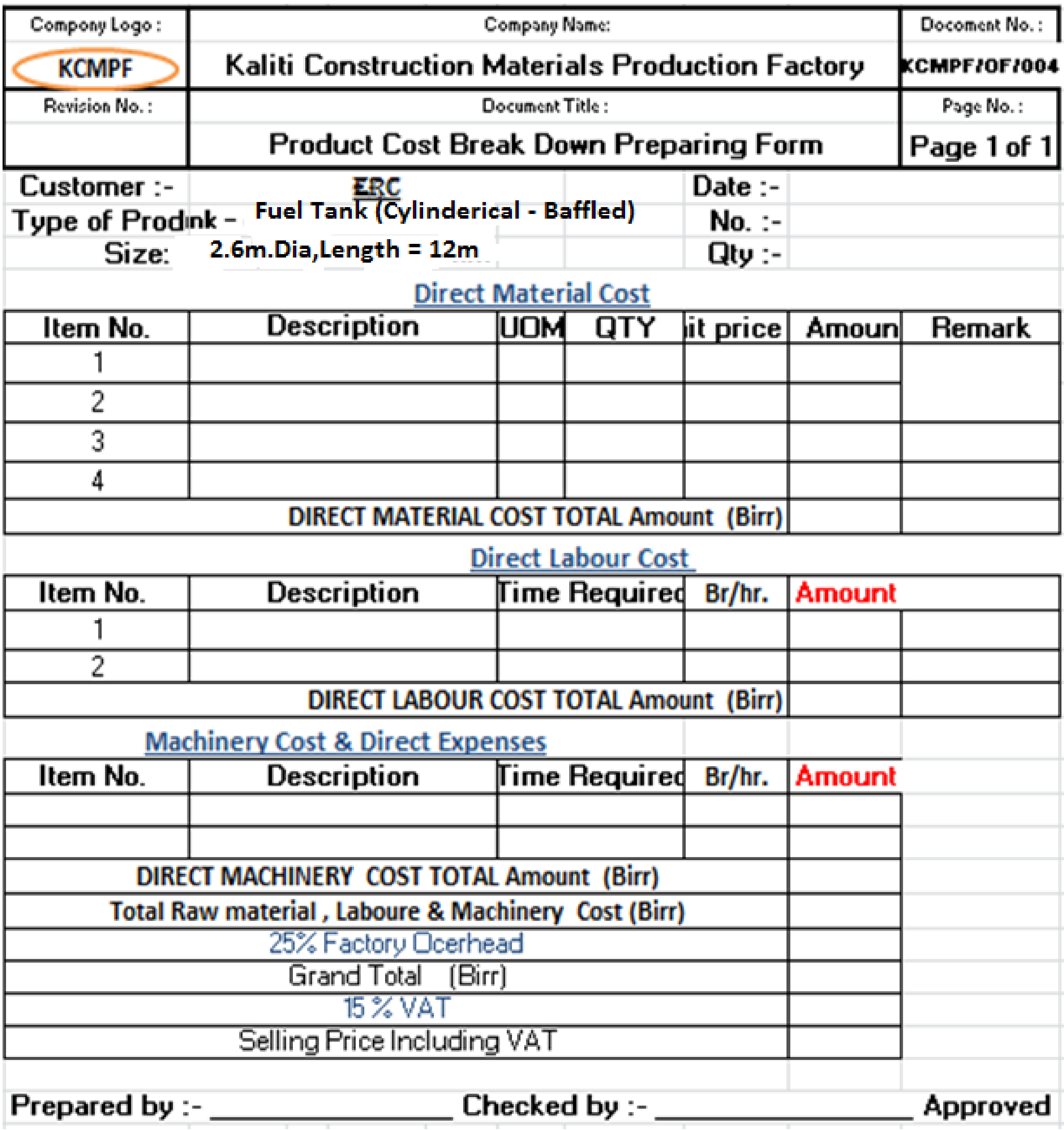
7. Appendixes

A. Cost Break-down sheet – KCMPF



Company Logo :	Company Name:	Document No. :
KCMPF	Kaliti Construction Materials Production Factory	KCMPF/OF/004
Revision No. :	Document Title :	Page No. :
	Product Cost Break Down Preparing Form	Page 1 of 1

Customer :-	ERC	Date :-	
Type of Prodink –	Fuel Tank (Cylinderical - Baffled)	No. :-	
Size:	2.6m.Dia,Length = 12m	Qty :-	

Direct Material Cost

Item No.	Description	UOM	QTY	it price	Amoun	Remark
1						
2						
3						
4						
DIRECT MATERIAL COST TOTAL Amount (Birr)						

Direct Labour Cost

Item No.	Description	Time Required	Br/hr.	Amount	
1					
2					
DIRECT LABOUR COST TOTAL Amount (Birr)					

Machinery Cost & Direct Expenses

Item No.	Description	Time Required	Br/hr.	Amount
DIRECT MACHINERY COST TOTAL Amount (Birr)				
Total Raw material , Laboure & Machinery Cost (Birr)				
25% Factory Ocerhead				
Grand Total (Birr)				
15 % VAT				
Selling Price Including VAT				

Prepared by :- ________________ Checked by :- ________________ Approved

B. Realizable *k*- ε equations

Distinctions from standard *k*-ε model:

- Alternative formulation for turbulent viscosity:

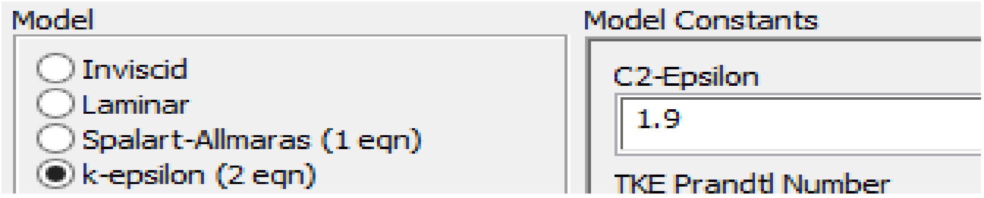
$$\mu_t \equiv \rho C_\mu \frac{k^2}{\varepsilon} \quad \text{where} \quad C_\mu = \frac{1}{A_o + A_s \frac{U^* k}{\varepsilon}} \quad \text{is now variable.}$$

  - (A_0, A_s, and U^* are functions of velocity gradients).

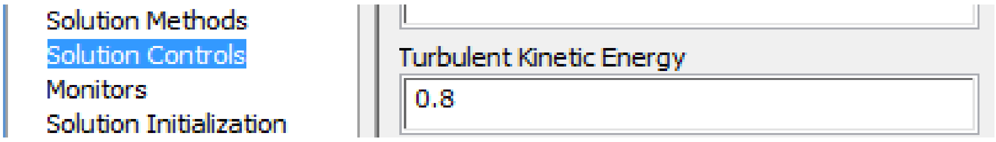
ε is ranging from 1.44 to 1.92,

ρ ***is approximately* 0.843 *for diesel,***

C_μ **is 0.09 constant**


Model
○ Inviscid
○ Laminar
○ Spalart-Allmaras (1 eqn)
● k-epsilon (2 eqn)

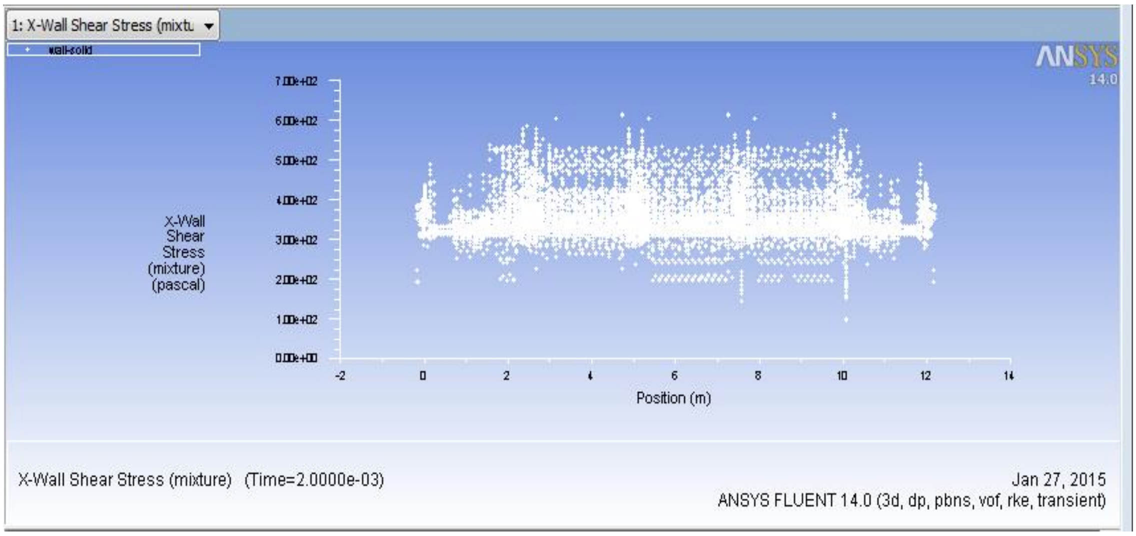
Model Constants
C2-Epsilon
1.9
TKE Prandtl Number



Turbulent Kinetic Energy
0.8

C. Total Velocity and Shear stress diagrams – Ansys

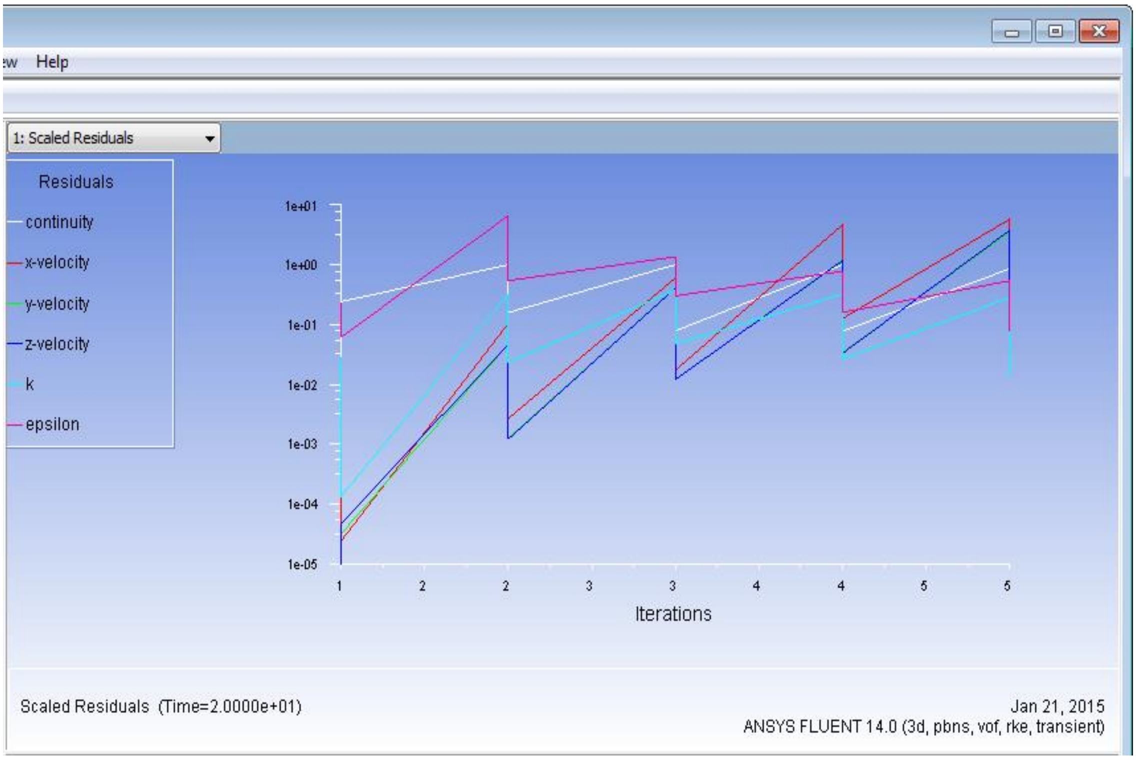
- Shear stress graph at walls



X-Wall Shear Stress (mixture) (Time=2.0000e-03)

Jan 27, 2015
ANSYS FLUENT 14.0 (3d, dp, pbns, vof, rke, transient)

- Total velocity graph - Ansys

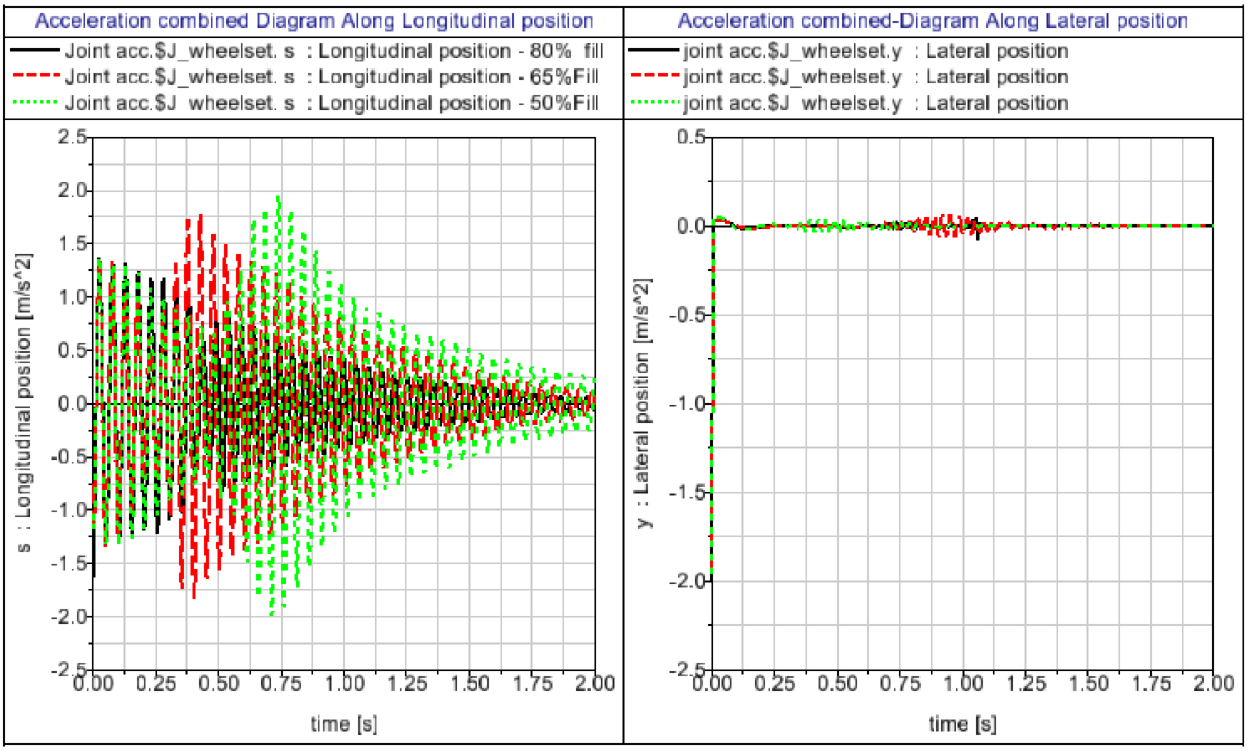


Scaled Residuals (Time=2.0000e+01)

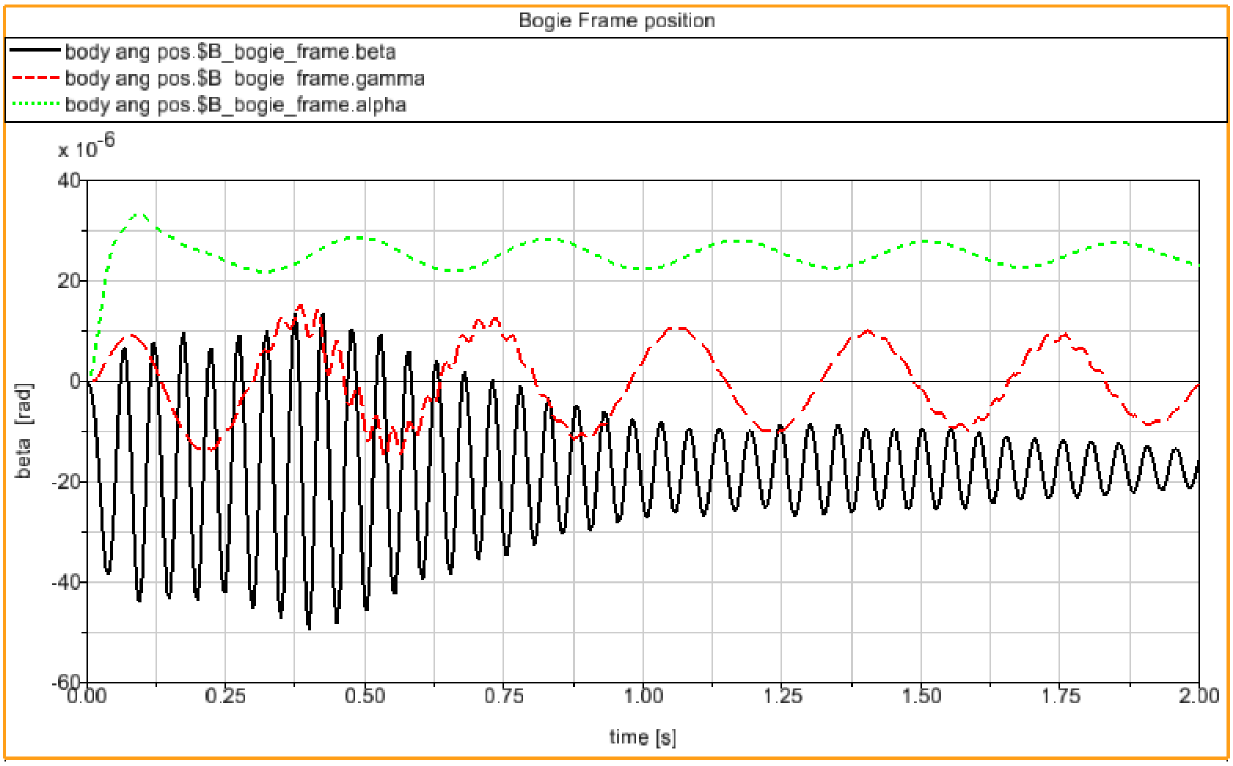
Jan 21, 2015
ANSYS FLUENT 14.0 (3d, pbns, vof, rke, transient)

D. Combined results of Simpack acceleration and angular position – 90km/hr

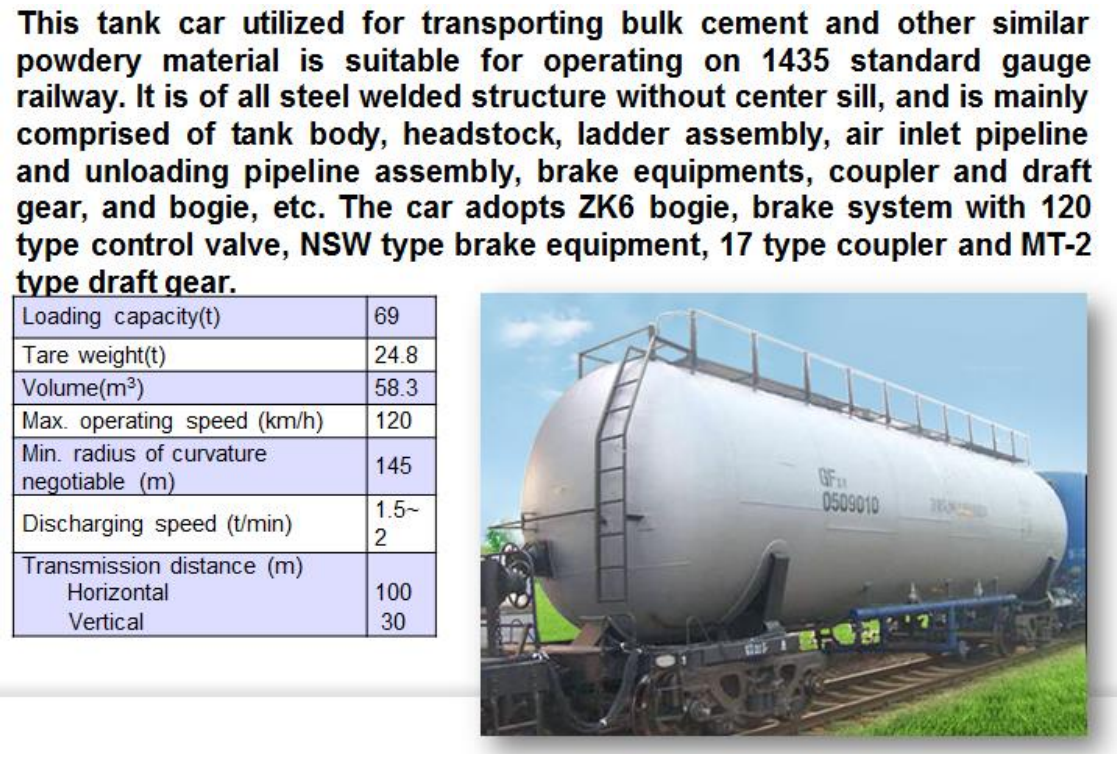
Combined lateral and longitudinal accelerations of different fill-levels - Simpack



Bogie Frame angular position combined results – 65% fill and 120km/hr



E. Bulk Cement Tank Car



This tank car utilized for transporting bulk cement and other similar powdery material is suitable for operating on 1435 standard gauge railway. It is of all steel welded structure without center sill, and is mainly comprised of tank body, headstock, ladder assembly, air inlet pipeline and unloading pipeline assembly, brake equipments, coupler and draft gear, and bogie, etc. The car adopts ZK6 bogie, brake system with 120 type control valve, NSW type brake equipment, 17 type coupler and MT-2 type draft gear.

Loading capacity(t)	69
Tare weight(t)	24.8
Volume(m^3)	58.3
Max. operating speed (km/h)	120
Min. radius of curvature negotiable (m)	145
Discharging speed (t/min)	1.5~ 2
Transmission distance (m) Horizontal Vertical	 100 30

Technical Specification of Tank Wagon

The vehicle with the loading capacity 70t is mainly used for transporting the light oil medium over the line with the railway gauge 1435mm, such as the gasoline, kerosene and diesel, and the loading and unloading mode is the upper loading and upper unloading mode.

Key Parameters and Dimensions

Loading Capacity ----70t

Dead weight =25t

Volume ------------ 83m^3

Design Speed ----- 120km/hr

Minimum Curve Radius ------- 145m

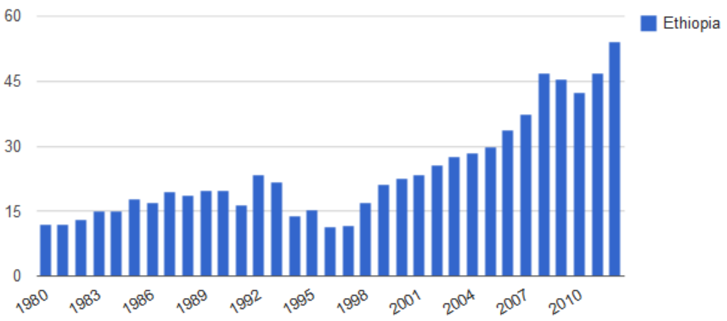
Vehicle Length (at Coupler Connection Point) = 13000mm

Height from Center of Coupler to Top of Rail (Empty Vehicle) ---- 880mm limit It complies with the regulation of GB146.1 Limit of Rolling Stock with Standard Gauge.

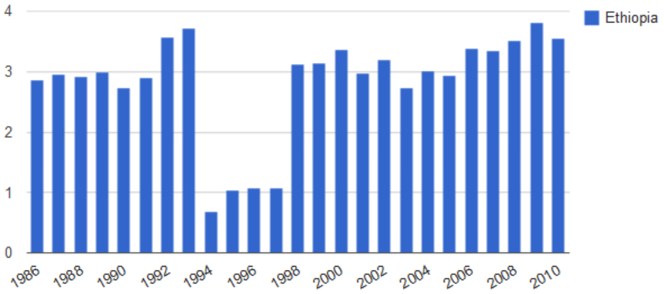
F. Ethiopia Oil consumption

(Thousand barrels per day, source: The U.S. Energy Information Administration)

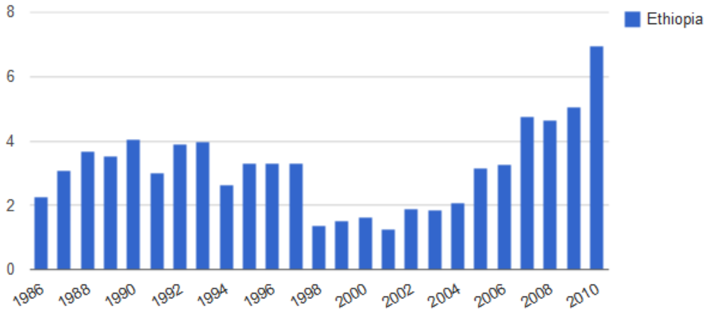
Ethiopia petroleum Oil consumption, thousand barrels per day: For that indicator, The U.S. Energy Information Administration provides data for Ethiopia from 1980 to 2012. The average value for Ethiopia during that period was 24.16 thousand barrels per day with a *minumum of 11.56 thousand barrels per day in 1996* and a *maximum of 54.11 thousand barrels per day in 2012*.



Ethiopia Gasoline consumption, thousand barrels per day: For that indicator, The U.S. Energy Information Administration provides data for Ethiopia from 1986 to 2010. The average value for Ethiopia during that period was 2.83 thousand barrels per day with a *minumum of 0.69 thousand barrels per day in 1994* and a *maximum of 3.81 thousand barrels per day in 2009*.



Ethiopia Jet fuel consumption, thousand barrels per day: For that indicator, The U.S. Energy Information Administration provides data for Ethiopia from 1986 to 2010. The average value for Ethiopia during that period was 3.18 thousand barrels per day with a *minumum of 1.28 thousand barrels per day in 2001* and a *maximum of 6.95 thousand barrels per day in 2010*.



DECLARATION

I hereby declare that the work which is being presented in this thesis entitled "**DYNAMIC SIMULATION OF FLUID SLOSHING EFFECTS on FLUID FREIGHT-WAGON**" is original work of my own, has not been presented for a degree in any other university; and that all sources of material used for the thesis are original and have been duly acknowledged.

Solomon Abera Tadesse	--------------------	--------------------
(Candidate)	Signature	Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

____________________	____________________
Dr. Daniel Tilahun (Advisor)	Date

Submitted to**:**

Addis Ababa University, Addis Ababa Institute of Technology (AAiT)