AKADEMIA GÓRNICZO-HUTNICZA

Railway Design, Simulation and Analysis by ADAMS/ Rail Software

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1. INTRODUCTION AND OBJETIVES

A train running along a track is one of the most complicated dynamical systems in engineering. Many bodies comprise the system and so it has many degrees of freedom. The bodies that make up the vehicle can be connected in various ways and a moving interface links the vehicle to the track. This interface involves the complex geometry of the wheel tread and the rail head and non-conservative frictional forces generated by relative motion in the contact area.

It is important to make a good design, simulation and analysis of a template if we want to improve, for instance, the railway parameters in order to make it more comfortable for the passengers, to amplify the velocity or to decrease the pollution.

It is useful to use a template to research into this kind of project: it is much cheaper, easier and quicker than doing it with a real model.

In order to make this kind of design, simulation and analysis railway, it is possible to use the great amount of software available. ADAMS/ Rail will be used to perform this Master Thesis.

The objectives of this Master Thesis, as the title already states are, firstly, designing a Template and then afterwards, performing some Simulations. Preload Simulation will be done as well as Linear Simulation, Stability Simulation and Dynamic Simulation. In the end, an analysis of the results will be obtained.

2. SOFTWARE USED: ADAMS/RAIL

It is possible to say that the computer simulation began in the aerospace industry using routines to calculate the flutter of an airplane wing. In 1962, it conducted the first analysis of eigenvalues of a two-axle vehicle. This analysis was carried out on a computer of the English Electric Aviation, by typical routine use in the aerospace industry, since the linear equations movement of a rail vehicle are the same as the aero elastic equations wing of an airplane, as long as they do a good interpretation of the speed vehicle.

With the passage of time and the increasing use of computers in the branch of engineering, it was increasing interest in the use of numerical methods, obtaining library standard routines for solving the eigenvalues and the solution of necessary differential equations. For this reason, from the 60's and 70's, began to perform simulations of nonlinear vehicle models complex. These simulations were based on the use of the equations of motion deduced manually and incorporated into computer programs. Subsequently large companies began to design packages that covering a wide range of dynamic calculations for the same model of vehicle. As which began to appear a lot of simulation programs that can be classified according to their approach:

- **First approach**: The equations were developed to address some more or less standard configurations, depending on their expected behavior.

- **Second approach**: allow the simulation of different vehicle models in general situations, obtaining the so-called multibody programs. Currently, the simulation process generally consists of four steps: Entering values, modelling, analysis and result output.

Success in the simulation comes mainly from the proper modelling of both the road as the vehicle and the proper input of data necessary to order to obtain the desired results. In short, it must take into account number of factors before determining the appropriate simulation program:

- Purpose of the simulations, including parameters and the required output accuracy.
- Frequency range of interest.

- Access to appropriate simulation packages.
- Access to important data models.
- Time and funding available.

ADAMS/Rail is a specialized environment for modelling rail vehicles. It allows you to create virtual prototypes of rail vehicle, and analyze the virtual prototypes much like it would analyze the physical prototypes.

ADAMS/Rail has two modes:

- **Standard Interface** - It is possible to use it when working with existing templates to create and analyze your rail models.
- **Template Builder** - If it have expert user privileges, it is possible to use ADAMS/Rail Template Builder to create new templates to be used in the ADAMS/Rail Standard Interface.

Using ADAMS/Rail, It can quickly create assemblies of rail vehicles, and then analyze them to understand their performance and behavior.

It is possible to create assemblies in ADAMS/Rail by defining vehicle subsystems, such as front and rear bogies (including wheelsets, bogie frames, primary and secondary suspensions, dampers, and anti-roll bars) and bodies. It bases these subsystems on their corresponding standard ADAMS/Rail templates.

It will can also base the subsystems on custom templates that it creates using the ADAMS/Rail Template Builder.

When it analyzes an assembly, ADAMS/Rail applies the analysis inputs that it will specify. For example, for a nonlinear comfort analysis it can specify as inputs:

- Nonlinear wheel/rail contact model
- Speed
- Track irregularities description based on measured data

Based on the analysis results, it can quickly alter the stiffness properties of the suspensions or the characteristic of the vertical dampers and analyze the rail model again to evaluate the effects of the alterations. For example, it is possible to change the position of the anti-yaw dampers to see which yields the best handling characteristics for the vehicle.

Once it complete the analysis of the model, it is possible to share the work with others. It can also print plots of the vehicle dynamic responses. In addition, it can access other users models without overwriting their data.

ADAMS/Rail enables to work faster and smarter, letting it have more time to study and understand how design changes affect vehicle performance. Using ADAMS/Rail it can:

- Explore the performance of the design and refine the design before building and testing a physical prototype.
- Analyze design changes much faster and a lower cost than physical prototype testing would require.
- Vary the kinds of analyses faster and more easily than if it had to modify instrumentation, test fixtures, and test procedures.
- Work in a more secure environment without the fear of losing data from instrument failure or losing testing time because of poor weather conditions.

This chapter has been written with the help of references [6], [7] and [10].

3. HISTORY DEVELOPMENT OF RAILWAYS

For this chapter have been used references [1], [2], [3], and [4].

3.1. THE PRECEDENT OF RAILWAYS

Even during the Renaissance, Leonardo da Vinci conceived, but never to realize his project, the first machine capable of moving without resorting to force an animal. Then in mid eighteenth century, the French inventor Jacques de Vaucanson, who had dedicated their efforts to design robots, conceived a sort of vehicle powered by a system similar to the clockwork. Soon after, a Swiss national priest J. H. Genevois, planned a similar device, powered by a somewhat bizarre procedure, two windmills, which provided small on top.

3.2. RAILWAY DEVELOPMENT

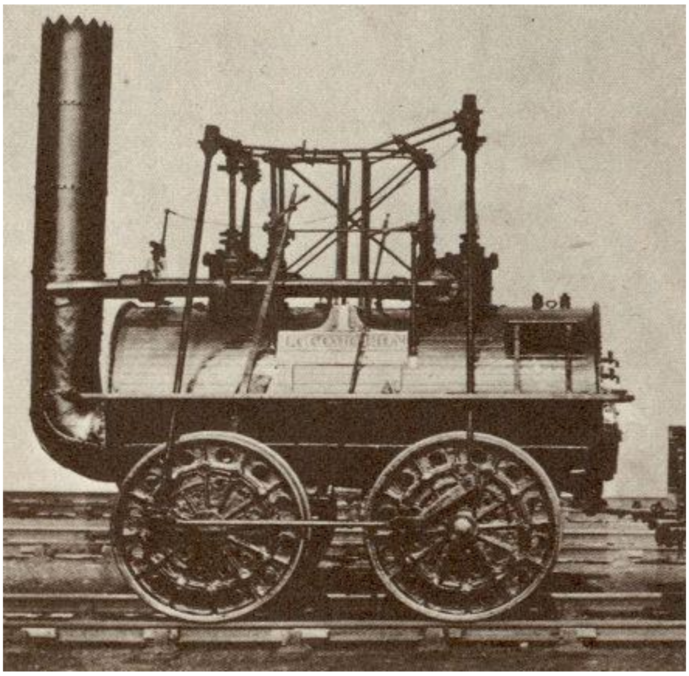
In the eighteenth century, workers from different mining areas in Europe found that loaded wagons moved more easily if the wheels were turning guided by a rail made of metal plates, because in this way reduced friction. The lanes for cars only served to move the product to the nearest waterway, which was then the main form of transporting large volumes. The start of the Industrial Revolution in Europe in the early nineteenth century, demanded more effective ways of bringing raw materials to the new factories and moved from such finished products.

The two mechanical principles, guiding wheels and use of motive power, were combined for the first time by the English mining engineer Richard Trevithick, who on February 24, 1804 succeeded in adapting the steam engine, used since the early eighteenth century to pump water, to pull of a locomotive was run at a speed of 8 km / h pulling five wagons, loaded with 10 tons of steel and 70 men on a road 15 km from the smelting of Pen-y-Darren , in South Wales.

Two decades passed during which they developed the cast-iron rails that supported the weight of a steam locomotive. The power required to pull trains, rather than one or two cars, secured by placing a steam locomotive on two or more axles with wheels attached by rods.

Finally, in 1825 was opened to the public the first steam railway: a set of wagons pulled by a locomotive used this power, covering the distance between the

English towns of Stockton and Darlington Five years later it was opened on Liverpool-Manchester flight Which said regular traffic of goods and passengers between the two locations, the locomotive, the famous Rocket, was built by the said Stephenson. With appropriate improvements, the prototype would be used in future machines.



Picture 1. First Railway [2]

A mid-nineteenth century were built many miles of track, around 1850 the steam railway had reached every continent.

The builders of Europe and North America in general adopted the width of 1,435 mm (56 inches and a half) of the proposed George Stephenson, which was based on the lines of way for mining trucks from their place of origin had been shown empirically dimension was the most suitable for towing by human or horses. International standardization of this broad did not occur until the Berne Conference of 1887.

3.3. NEW FORMS OF ENERGY APPLIED TO RAIL

Despite all the progress made, excess weight and volume of the steam engine and the high cost of facilities to supply fuel and water, coupled with the low performance and high degree of contamination of these machines, favored the emergence new technologies. Around 1940 the manufacture of steam engines was interrupted in America and Europe.

The first trains that used power from the late nineteenth century, the first railway of its kind was launched in 1881, near Berlin. However, the first regular rail service was the one who joined in 1895 Baltimore and Ohio in the United States

Picture 2. The First regular rail service [4]

4. DESIGN THE TEMPLATE

This chapter has been written with the help of reference [6].

4.1. INTRODUCTION

The simulation software ADAMS / Rail, is developed by MSC. Software Corporation specializes in the analysis of rail vehicles, as well as the different subsystems that constitute the model.

To create a model of Adams / Rail, it must define the various subsystems that form, for instance the bogies (each made up of wheels by the suspension primary and secondary buffers, etc) and railroad cars. These subsystems can be created by the user, using the creation mode templates, or it can use predefined templates for the program, facilitating the use of this software.

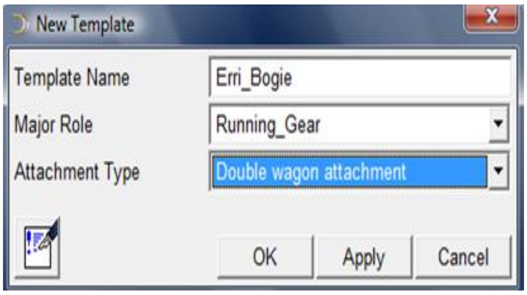
Adams / Rail is an appropriate tool to study and understand the behavior of the model, facilitating the exchange of properties different components that is, looking this way, the best solution possible, therefore, ADAMS / Rail allow:

- Improve the design before building the physical prototype.
- Analyze design changes much faster and at lower cost using physical prototypes.
- Realize a variety of analysis, so much easier than changing the instrumentation required in a real model.

4.2. CREATING A BOGIE TEMPLATE

It is necessary to create a template in which to build bogie parts. It should assign to the template a major role as a running gear template, because a major role defines the function the template serves for the vehicle.

To create a bogie template it is from *File* menu and the select *New*, and the *New Template* dialog box appears as below it can see:



Picture 3. New Template dialog box

A gravity icon appears in the middle of the ADAMS/Rail main window as shown:

Picture 4. A gravity icon

BUILDING BOGIE PARTS

It will create all the components using either the Railway Elements library.

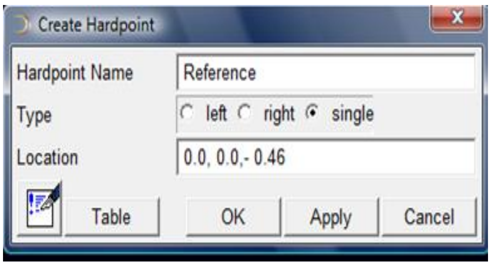
In ADAMS/Rail, it creates general parts through a three-step process. First, it creates hardpoints that define key locations on the part. Then, it creates the actual part.

4.2.1. WHEELSET

First it defines the wheelsets, and it begins by building a hardpoint. It can later modify this hardpoint to determine its effect on your vehicle.

Next, it will create a double wheelset and specify its coordinate system location, the wheels' property files, and the mass properties. It will specify the mass properties of a single wheelset. A double wheelset consists of two wheelsets that have the same mass properties and property files.

To building a hardpoint it will select *Build* menu→*Hardpoint* and then *New*, then it will appear the below dialog box:



Picture 5. Dialog box to Create Hardpoint

A double wheelset consists of the following objects:

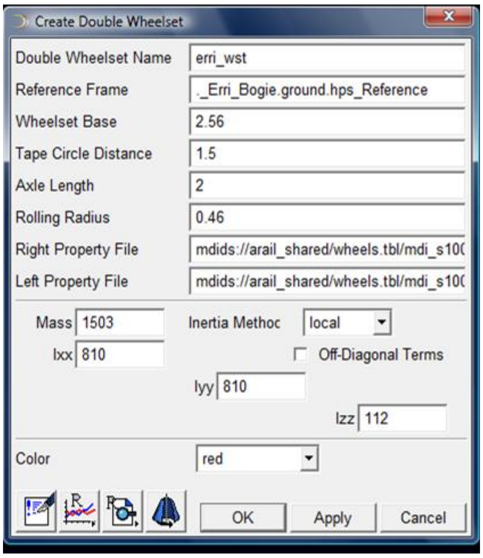
- Two parts for wheelsets (geometry included).
- Two strings for each wheelset in which the names of left and right property files are stored.
- Two strings for each wheelset in which the names of left and right contact configuration files are stored.
- Two arrays for each wheelset containing parameters driving the contact preload forces calculation in the first step of the analysis.

- Two arrays for every wheelset containing all the information about the wheel properties used to generate the reference parts for contact representation.
- An automatic set of requests that output all the interesting data during the dynamic analysis.

ADAMS/Rail creates the parts in such a way so as to be translated with respect to the reference frame of half the wheelbase distance in longitudinal (x) direction and sets the orientations to be 0º, 90º, 0º.

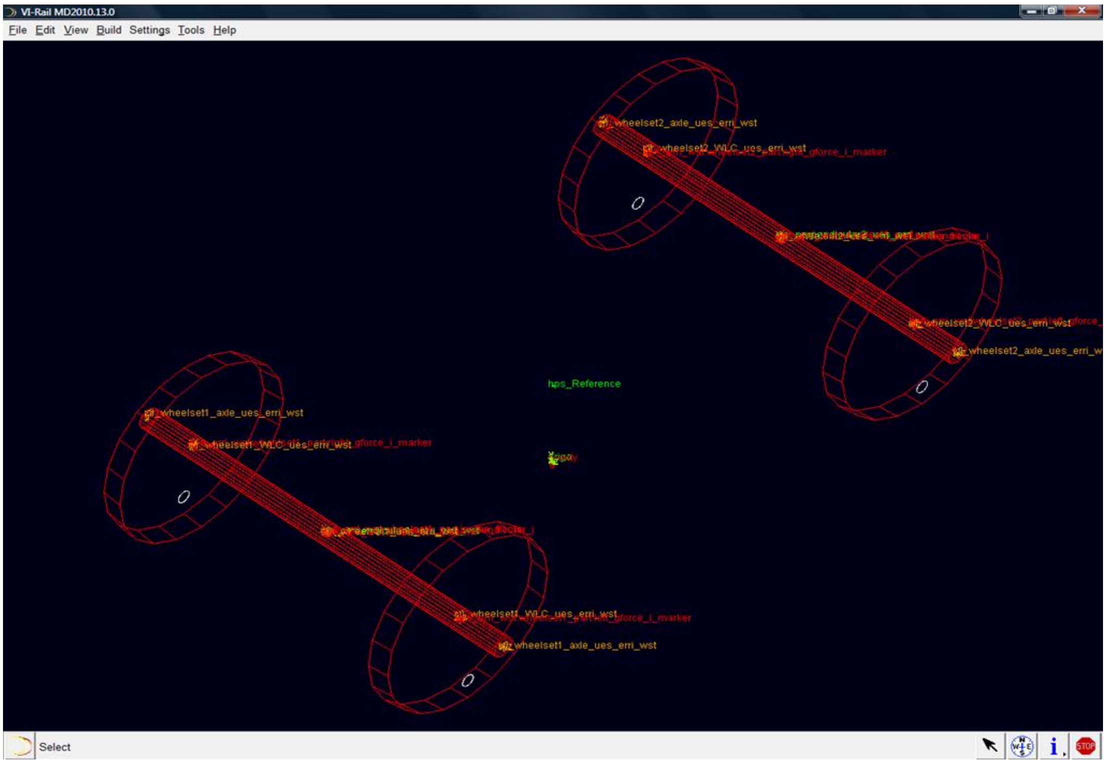
The center-of-mass (CM) location is coincident with the local part reference.

To create the wheelsets it will select the *Build* menu, point to *Railway Elements*, point to *Wheelset*, point to *Double Wheelset*, and then select *New*, then it will be appear the next dialog box:



Picture 6. Dialog Box to Create Double Wheelset

Following it can see the wheelset created, it is possible to see that it made double wheelset, as it told before. Also it checks with this picture that this program is working with element finite.



Picture 7. Double Wheelset

4.2.2. BOGIE FRAME

A bogie frame consists of one part that defines the bogie part and its geometry.

ADAMS/Rail creates the bogie frame in such a way so as to be centered between four construction frames, and it sets the orientation to be 0º, 0º, 0º.

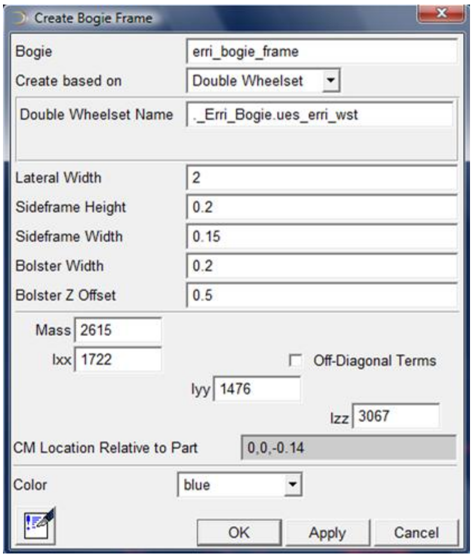
It can express the center-of-mass (CM) location in the part local reference frame. The orientation is always equal to the part orientation.

To create a bogie frame element in the Template Builder, it can specify the following parameters:

- Creation method
- Double wheelset

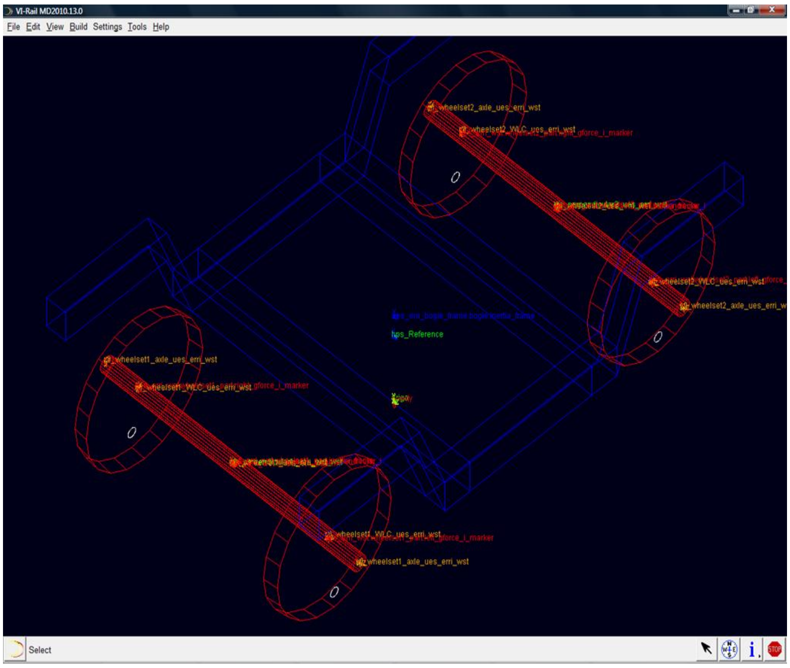
- Front left/right construction frame
- Rear left/right construction frame
- Mass and inertia properties of the bogie frame parts
- Bogie width
- Side frame height
- Side frame width
- Bolster width
- Bolster z displacement

To create the Bogie Frame: From the *Build* menu, point to *Railway Elements*, point to *Bogie Frame*, and then select *New*. After it will appear the dialog box below that it will fill with the next parameters how it shown:



Picture 8. Dialog Box to Create Bogie Frame

It can be seen the Bogie Frame made, it is the blue one. As shown the next picture the bogie frame is completely get-together to the double wheelset. To this manner it will make the bogie.



Picture 9.Bogie Frame

4.2.3. AXLE BOXES:

An axlebox consists of the following objects:

- One part with its geometry representing the axlebox.
- A variable storing the global position.
- Two variables used for the geometric parameters calculation.

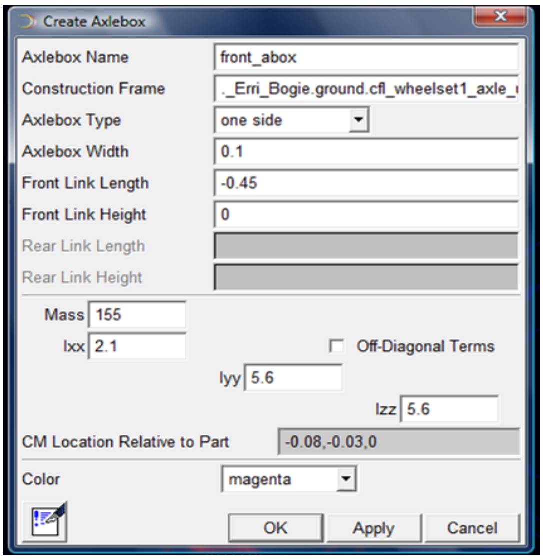
ADAMS/Rail creates the part in such a way so as to have the same location and orientation as the reference frame.

You can express the center-of-mass (CM) location in the part local reference frame. The orientation is always equal to the part orientation.

To create an axlebox element in the Template Builder, it can specify the following parameters:

- Reference frame defining the position and the orientation of the part and its geometry
- CM location relative to part (in three directions: x, y, and z)
- Mass and inertia properties of the axlebox parts
- Axlebox type
- Axlebox width
- Front link length
- Front link height
- Rear link length
- Rear link height

It can be seen it will fill the following parameters to create Front AxleBox:



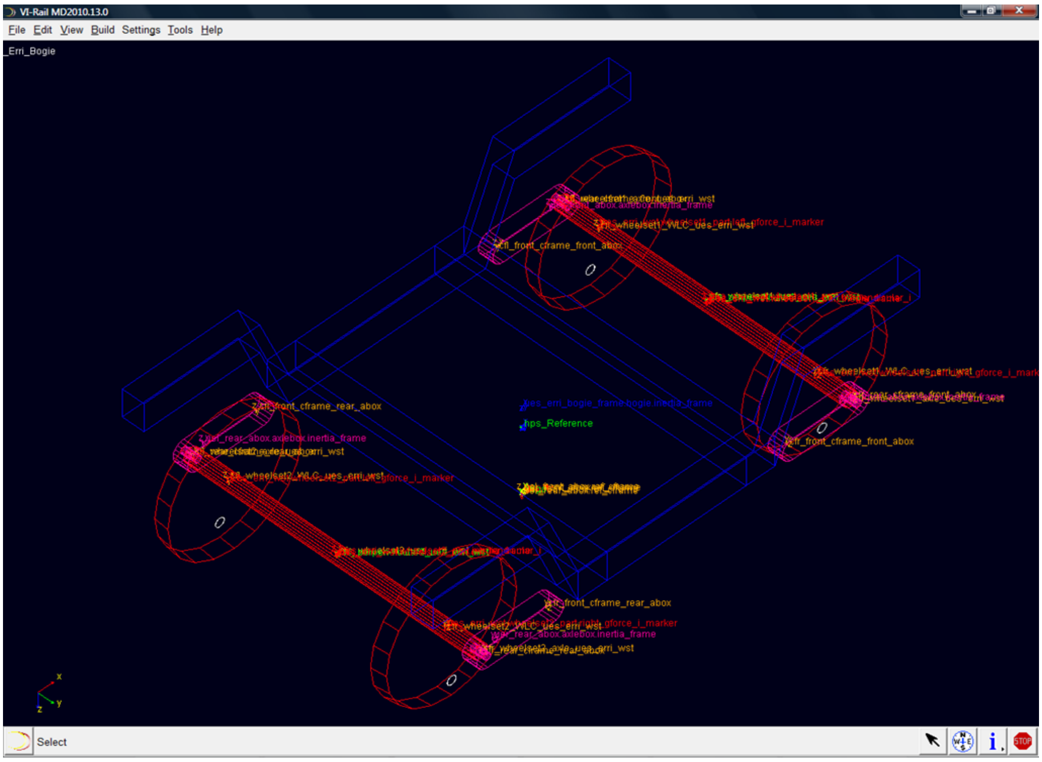
Picture 10. Dialog Box to Create Front Axlebox

And these are the parameters to create Rear Axle Box:

Axlebox Name	**rear_abox**
Construction Frame	._Erri_Bogie.ground.cfl_wheelset2_axle_ues_erri_ws
Front Link Length	0.45
CM Location Relative	0.08, -0.03, 0.0

Chart 1. Parameters of Rear Axlebox

Following it is shown the Axlebox created, as it said when the frame was created, the Axlebox are the pink draws. It is possible to perceive that the axlebox are perfectly positioned.



Picture 11. Axlebox

4.2.4. PRIMARY SUSPENSIONS:

A suspension element consists of the following objects:

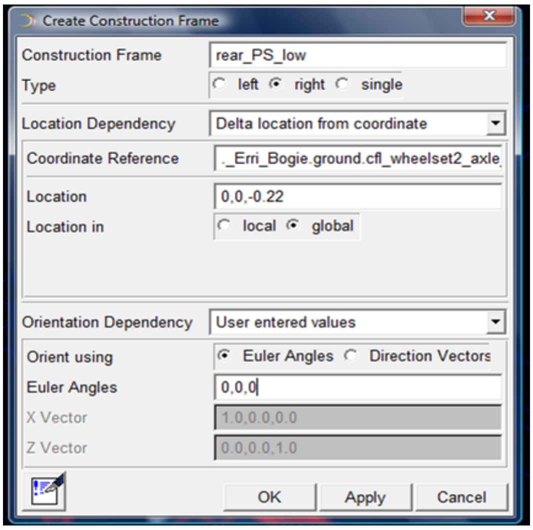
- A bushing.
- A preload force, used for the preload calculation.
- A spring-damper graphic.
- An array containing all the information about the bushing parameters.
- Bushing parameters.
- A displacement request.
- A velocity request.
- A force request.

The suspension component is defined as a bushing with linear stiffness and a linear damping calculated using a damping factor.

To create a suspension element in the Template Builder, it can specify the following parameters:

- I and J parts, between which the suspension component acts
- I and J coordinate reference (they cannot have the same location)
- Property file in which all the information about suspension component is stored
- Translational preload in three directions x, y, and z
- Geoscale (scale factor for the spring-damper geometry)
- Numcoils (the number of coils for the spring-damper geometry)

To create the primary suspensions, it necessary first to create the construction frames with the parameters shown in the next dialog box:



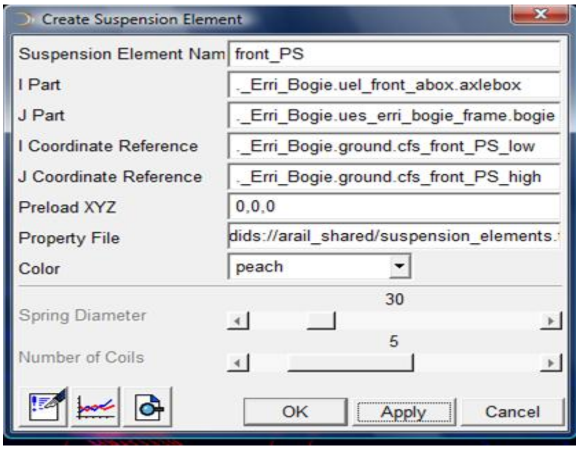
Picture 12. Dialog box to create construction frame of the Primary Suspensions

To create the rest of the construction frames modifying the following:

Construction Frame	Coordinate Reference	Location
rear_PS_high	cfr_wheelset2_axle_ues_erri_wst	0, 0, -0.48
front_PS_low	cfr_wheelset1_axle_ues_erri_wst	0, 0, -0.22
front_PS_high	cfr_wheelset1_axle_ues_erri_wst	0, 0, -0.48

Chart 2.Parameters of Primary Suspensions

Following it will build the suspensions; it will fill the dialog box as it can be seen:



Picture 13. Dialog Box to Create Suspension Element

The same manner it will fill the rear one.

4.2.5. SECONDARY SUSPENSIONS

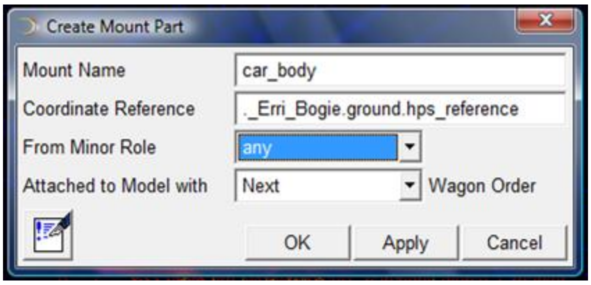
Before it create the secondary suspensions for the bogie, it is necessary to create the mount part that connects to the wagon part during assembly. A mount part is a mass less part, fixed to ground by default. This mount part represents the wagon part and acts as a place holder for it.

When it creates a mount part, ADAMS/Rail automatically creates an input communicator for it of class mount. The input communicator requests the name of the part to which the mount part should connect. If ADAMS/Rail finds a matching communicator during assembly, it attaches the mount part to the part that the output communicator indicates. This part can be from another subsystem. If ADAMS/Rail does not find a matching output communicator, the mount part remains fixed to ground.

To create a mount part, it necessary to specify a hardpoint and a mount part name. If the hardpoint has a left or right symmetrical twin, ADAMS/Rail creates left and right mount parts and input communicators. Otherwise, it creates a single mount part and a single input communicator.

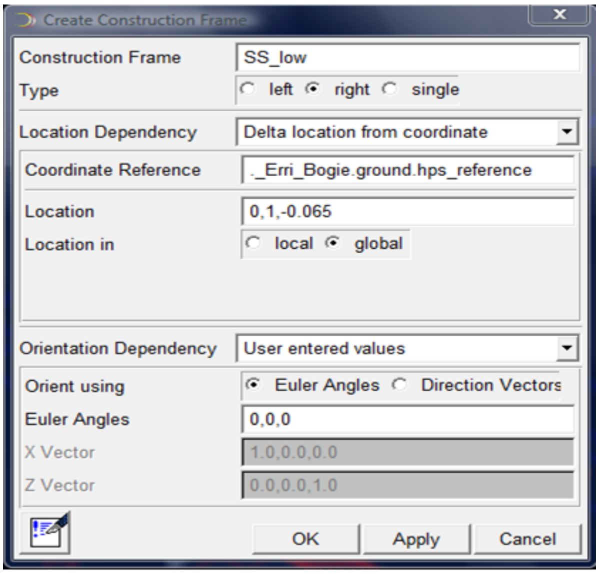
After it creates the mount part, it will create the secondary suspensions for the bogie. First it will create the construction frames and then use them to define the suspensions.

To create the Mount Part is necessary to fill a dialog box as it shown below:



Picture 14. Dialog Box to Create Mount Part

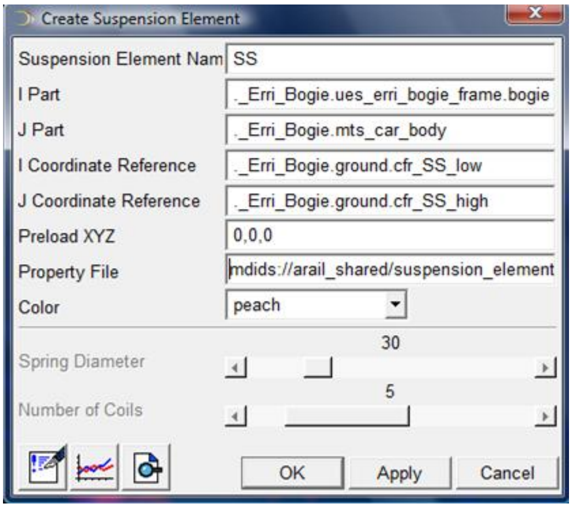
To build the construction frame it will fill the next dialog box:



Picture 15. Dialog Box to create Construction Frame

Create the other construction frame by modifying the name: “SS_high” and the location where it will fill: 0,-1,-0.67

And finally to build the secondary suspensions, it will fill the following dialog box:



Picture 16. Dialog box to create Suspension Element

4.2.6. CREATING THE VERTICAL, LATERAL, AND ANTI-YAW DAMPERS

A damper consists of the following objects:

- A single-component force.
- A spline in which the force - velocity curve is stored.
- A differential equation for the damping + series stiffness.
- A request.

The damper is defined as a single-component force. The expression of this force depends on which kind of damping method you want to specify.

The damping type can be:

- Linear damping
- Linear damping series stiffness
- Nonlinear damping
- Nonlinear damping series stiffness

To create a damper element in the Template Builder, it can specify the following parameters:

- I and J parts, between which the damper acts
- I and J coordinate reference (they cannot have the same location)

- Damping type
- Linear damping
- Property file in which the force - velocity curve is represented
- Series stiffness
- Geoscale (scale factor for the spring-damper geometry)

First it will create the hardpoints and then use them, along with the property file. Property files define characteristics for springs, dampers, bumpstops, reboundstops, and bushings.

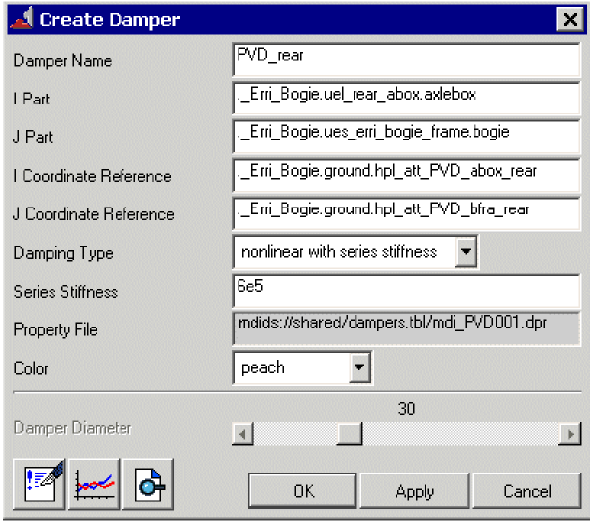
The following chart show the values of the hardpoints used:

Hardpoint Name	Location
att_PVD_bfra_front	1.55, -1, -0.88
att_PVD_abox_front	1.55, -1, -0.48
att_PVD_bfra_rear	1.55, -1, -0.88
att_PVD_abox_rear	1.55, -1, -0.48
att_LD_bfra	0, -0.23, -0.65
att_LD_body	0, -0.665, -0.75
att_SVD_bfra	0, -1.3, -0.4
att_SVD_body	0, -1.335, -0.925
att_YD_bfra	-0.23, -1.41, -0.525
att_YD_body	-1.106, -1.41, -0.630

Chart 3. Values of Hardpoints

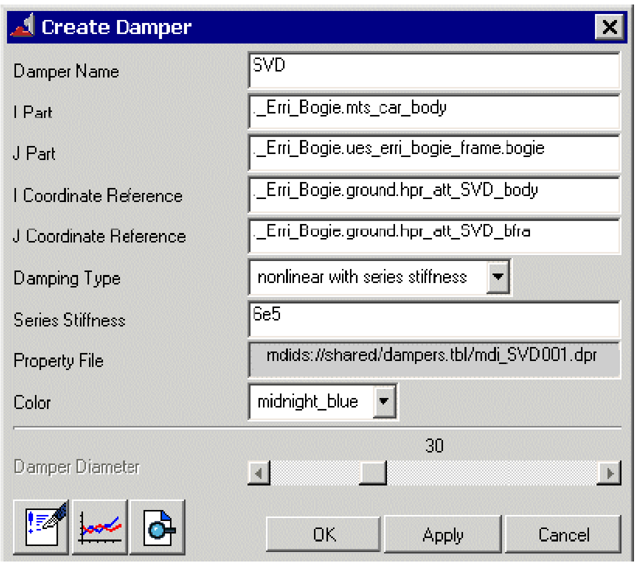
To create the vertical, lateral and anti-yaw dampers it necessary to fill the following dialog box how it shown:

- Primary vertical dampers: this is the dialog box that it has to fill to made the primary vertical dampers.



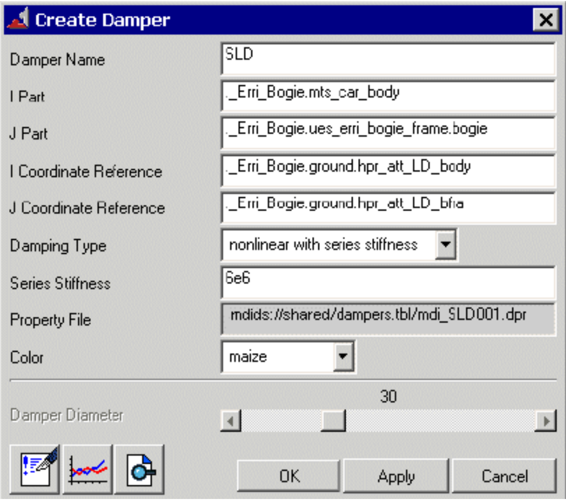
Picture 17. Dialog Box to create Primary Vertical Dampers

- Secondary vertical dampers: this is the dialog box that it has to fill to made the primary vertical dampers, is the same that the previous dialog box.



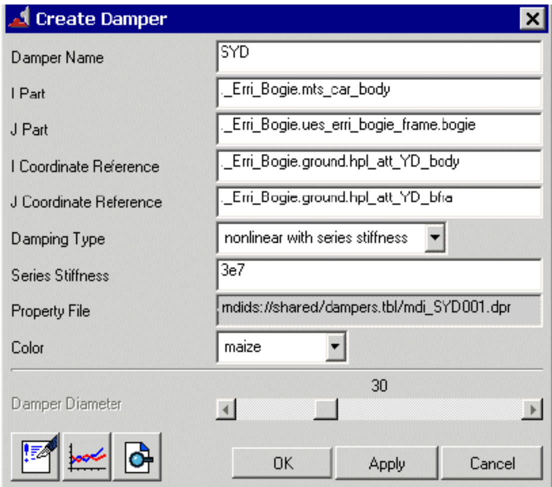
Picture 18. Dialog Box to create Secondary Vertical Dampers

- Lateral Dampers: this is the dialog box that it has to fill to made the primary vertical dampers.



Picture 19. Dialog Box to create Lateral Dampers

- Anti-yaw dampers: this is the dialog box that it has to fill to made the primary vertical dampers.

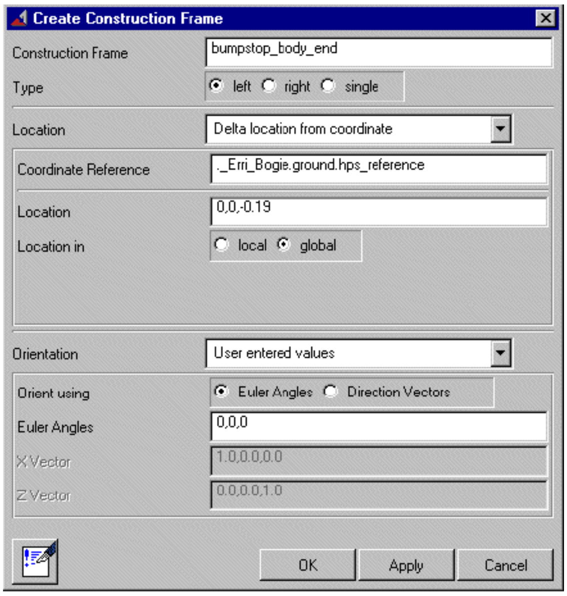


Picture 20. Dialog Box to create Anti-yaw Dampers

4.2.7. BUMPSTOPS

In this section, it will make the bumpstops. First it will create the construction frames and then use them to define the bumpstops.

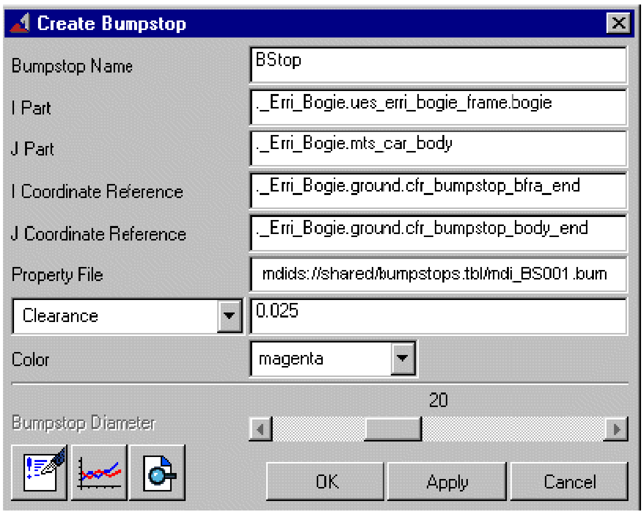
To build a construction frame it will fill the next dialog box:



Picture 21. Dialog Box to create the Construction Frame

Create the other construction frame by modifying the name: "bumpstop_bfra_end" and the location: 0,-0.15,-0.19.

To generate the bumpstops it fill in the dialog box as shown next:

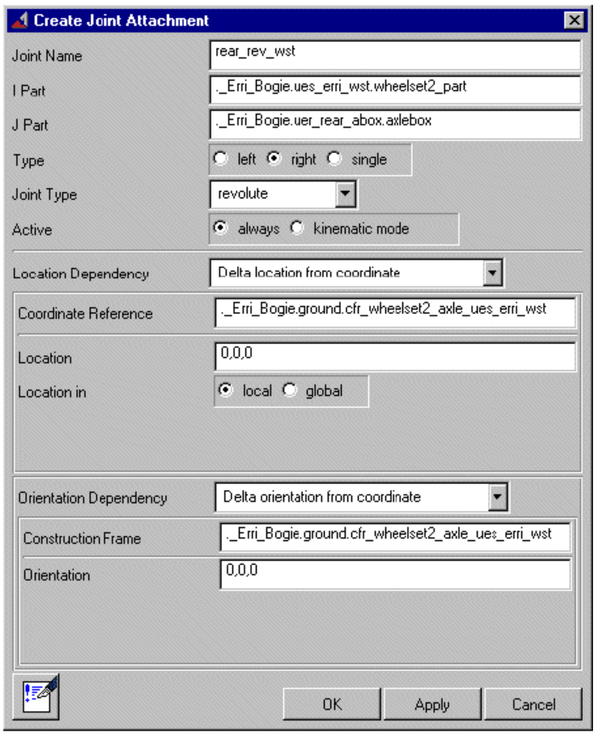


Picture 22. Dialog Box to create Bumpstop

4.2.8. REVOLUTE JOINTS

It will make revolute joints between each axle box and the corresponding wheelset.

To build the rear revolute joint it fills in the dialog box as shown next:



Picture 23. Dialog Box to create Rear Revolution Joints

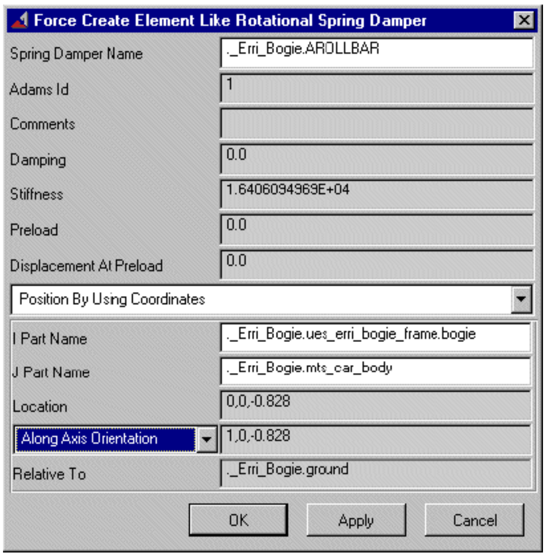
Create the front revolute joint by modifying the following chart:

Joint Name	front_rev_wst
I Part	._Erri_Bogie.ues_erri_wst.wheelset1_part
J Part	._Erri_Bogie.uer_front_abox.axlebox
Coordinate Reference	._Erri_bogie.ground.cfr_wheelset1_axle_ues_erri_wst
Construction Frame	._Erri_bogie.ground.cfr_wheelset1_axle_ues_erri_wst

Chart 4. Parameters of Front Revolute Joint

4.2.9. ANTI-ROLL BAR

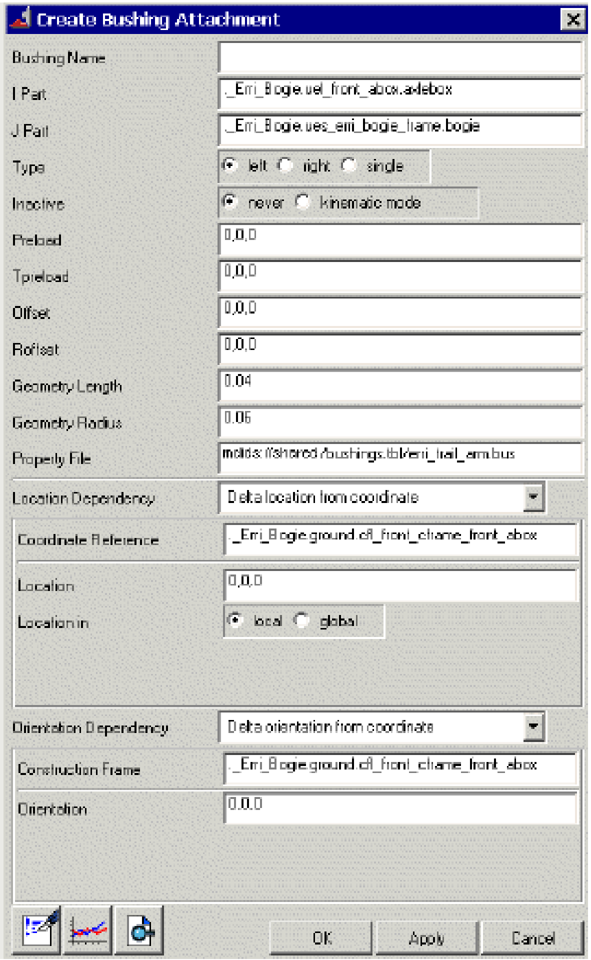
To create the anti-roll bar from the Tools menu, select Command Navigator, then select: force -> create -> element like -> rotational_spring_damper and it fill the dialog box below:



Picture 24. Dialog Box to create Anti-Roll Bar

4.2.10. TRAILING ARM BUSHINGS

Bushings are six-component stiffness elements defined with nonlinear characteristics. It defines bushings by specifying two parts to be connected and a location. It will fill the next dialog box:



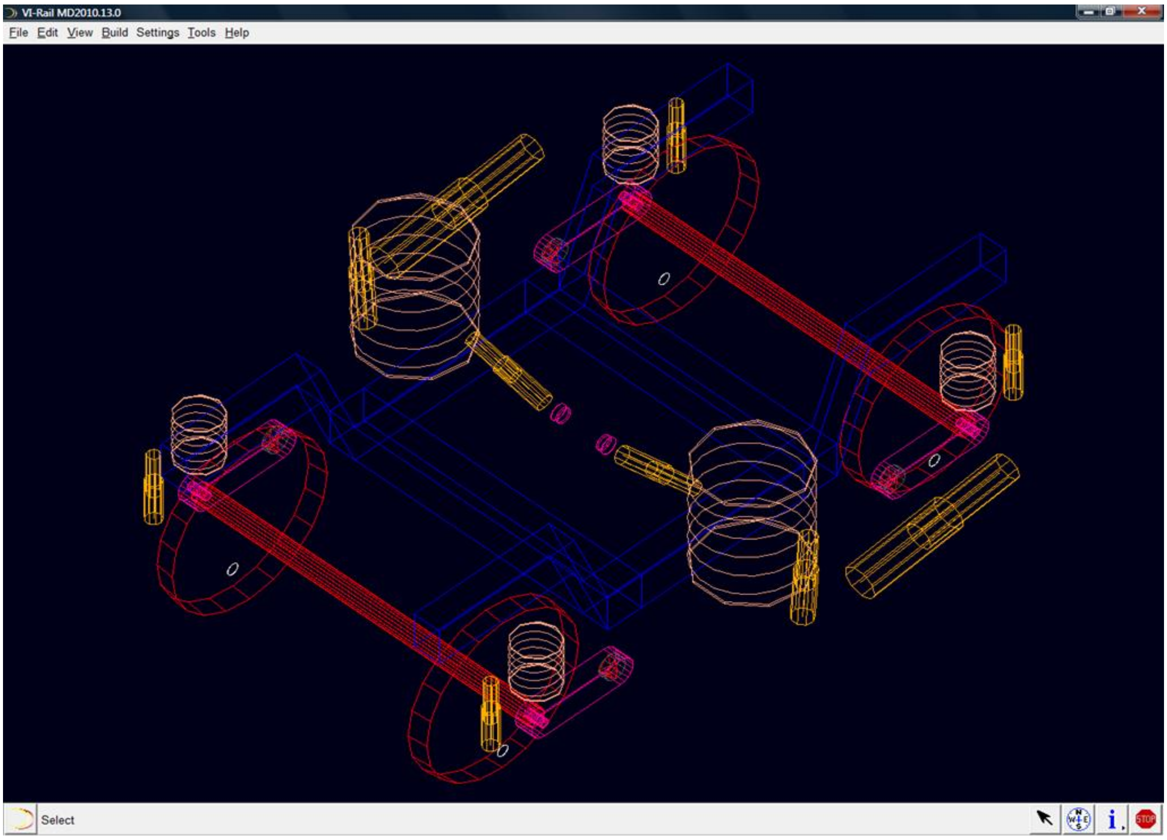
Picture 25. Dialog Box to create Trailing Arm Bushings

Create the two rear trailing arm bushings by modifying the following:

Bushing Name	**rear_trail_bush**
I Part	._Erri_Bogie.uel_rear_abox.axlebox
Coordinate Reference	._Erri_Bogie.ground.cfl_front_cframe_rear_abox
Construction Frame	._Erri_Bogie.ground.cfl_front_cframe_rear_abox

Chart 5. Parameters of the two Rear Trailing Arm Bushings

Finally the Bogie models it is shown below. In this picture it can be seen every bogie elements, all of them explained before how to make it. It is possible to see that all elements are situated in their correct position; also, it has chosen one color to each element to better difference, just in case there is any mistake and can modify it easily.



Picture 26. Bogie Model

4.3. CREATING A TEMPLATE FOR THE CAR BODY

A car body standard wagon consists of the following objects:

- One part defining the body part.
- One part without mass defining the body geometry.
- A fixed joint between the two parts.

ADAMS/Rail creates the body wagon in such a way so as to have the same location as the reference frame, and sets the orientation to be 0º, 0º, 0º.

A vertical offset translates the geometry part location with respect to the body part. The orientation is the same as that of the body part.

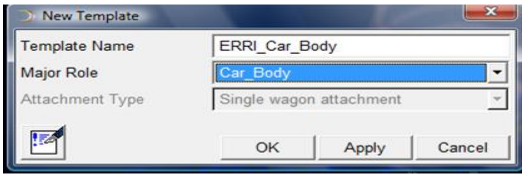
It can express the center-of-mass (CM) location in the part local reference frame. The orientation is always equal to the part orientation.

To create a body wagon element in the Template Builder, it can specify the following parameters:

- Reference frame defining the position of the part and its geometry
- CM location relative to part (in three directions: x, y, and z)
- Mass and inertia properties of the car body part
- Graphical vertical offset

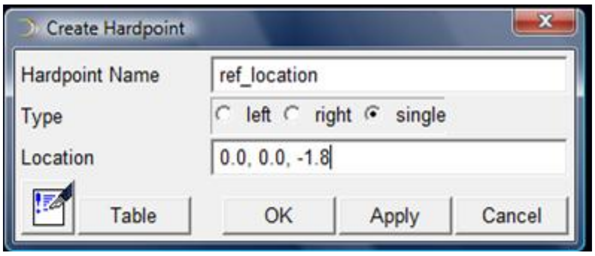
It assigns to the template the major role of *Car_body*, because a major role defines the function the template serves for the vehicle..

First it will create a new template how it shown in the next dialog box:



Picture 27. Dialog Box to create a New Template

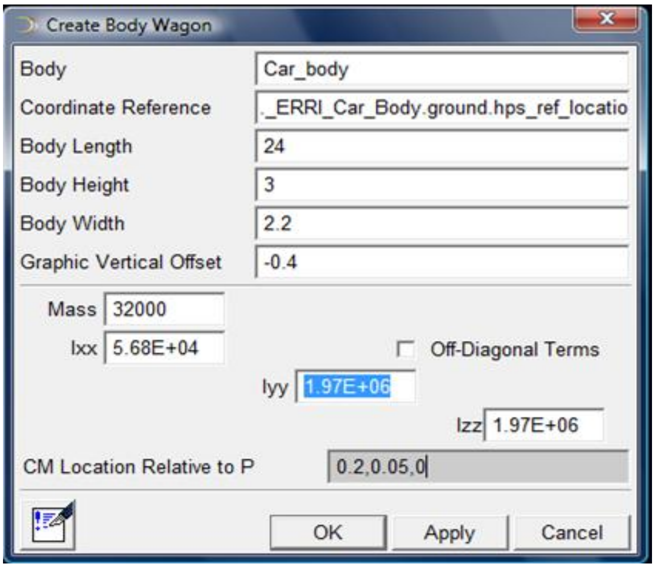
Before create the wagon part, it necessary to create a hardpoint for it



Picture 28. Dialog Box to create Hardpoint

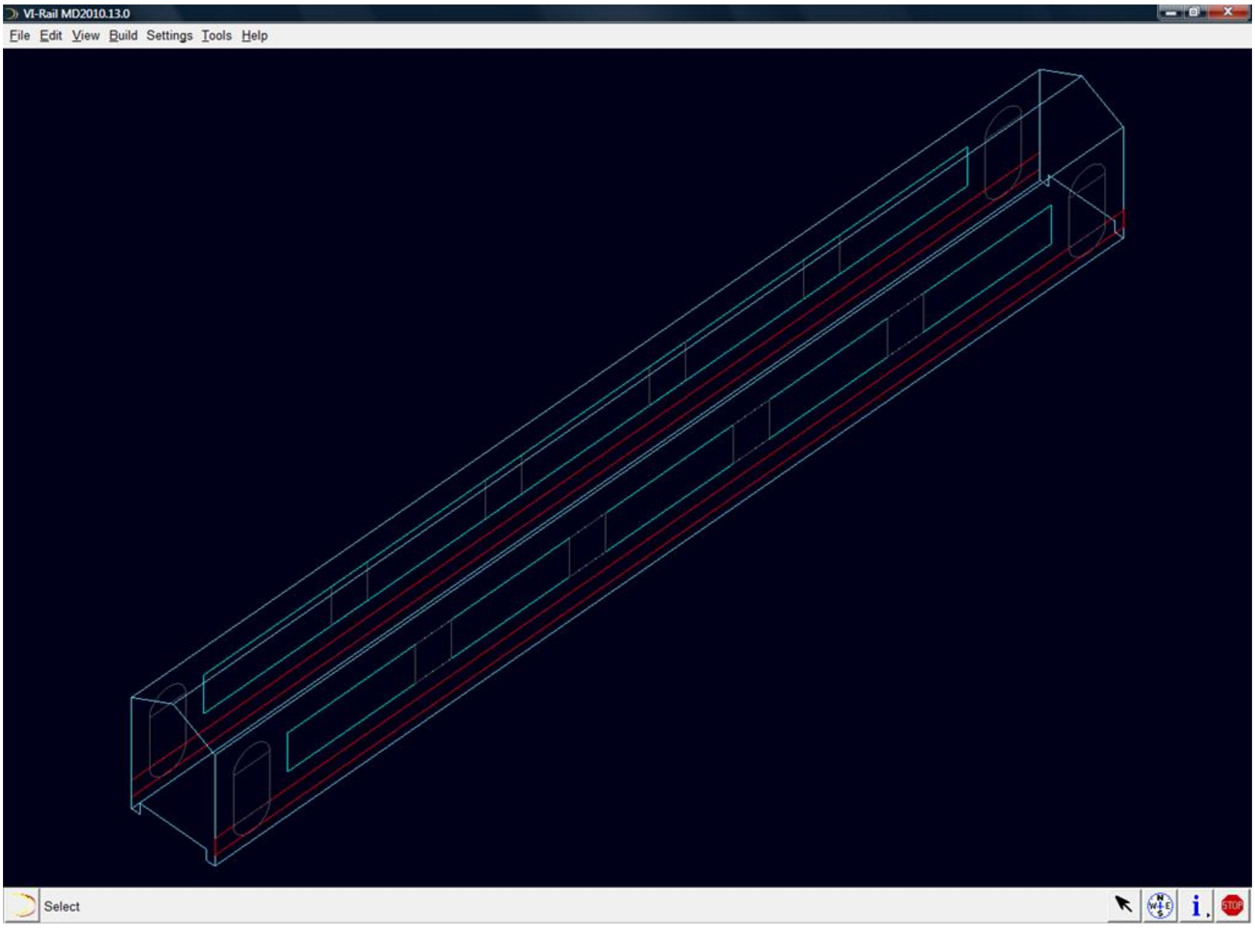
To produce the wagon part it selects from the *Build* menu, point to *Railway Elements*, point to *Car Body*, point to *Passenger Wagon*, and then select *New.*

It will fill in the dialog box as shown next, and then select OK.



Picture 29. Dialog Box to create Body Wagon

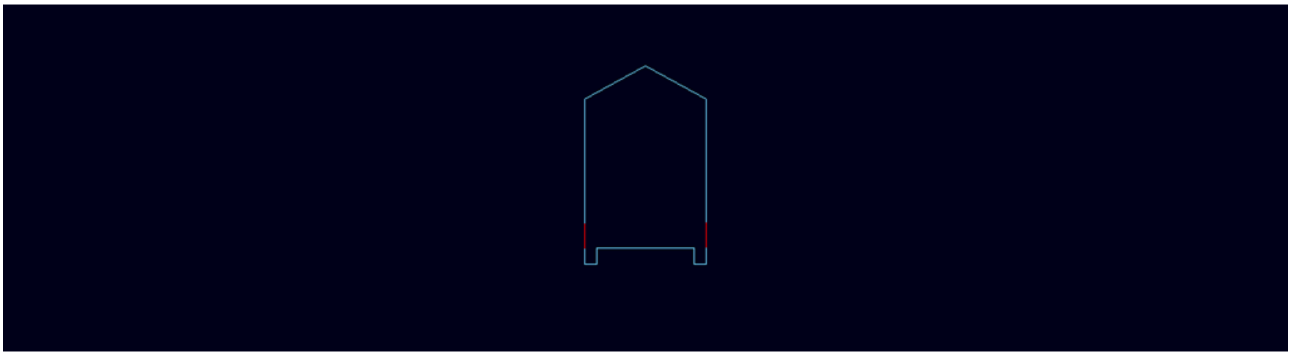
It is possible to see the final model below:



Picture 30.Template for de Car Body

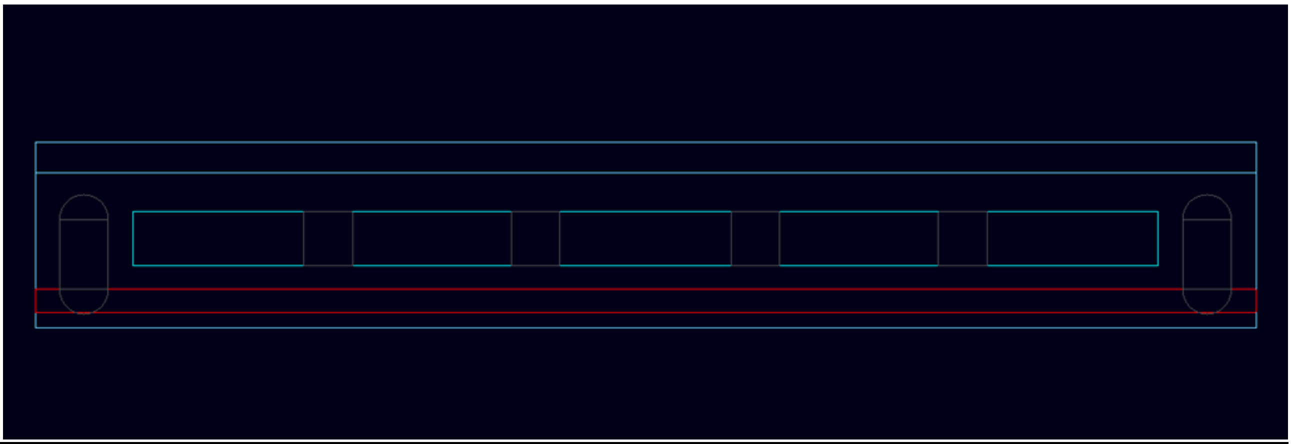
Following it can be seen the different views of the car body:

- Front: In the picture following it is shown the front view of the car body created.



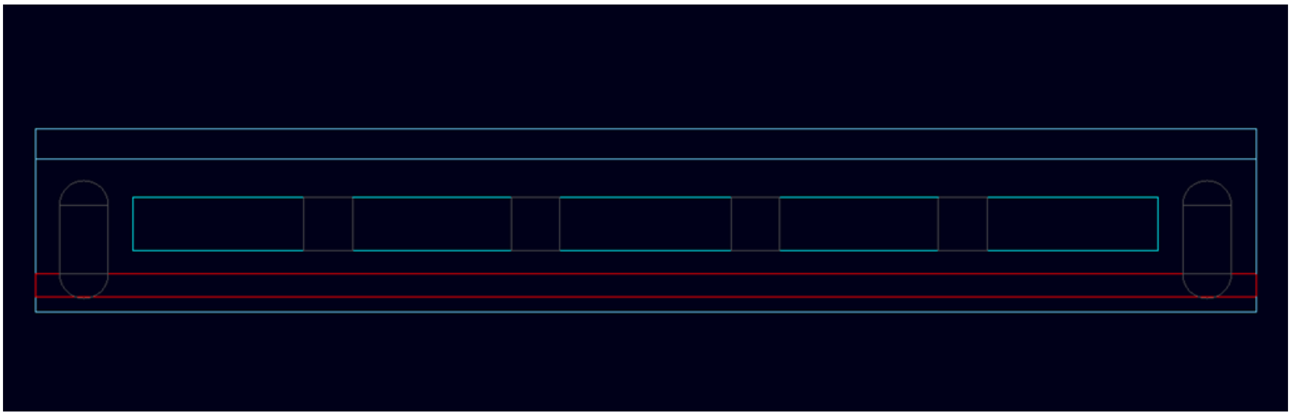
Picture 31.Front view

- Left side: The next picture is the left side, it will be the same that the right side, as is a railway, and this kind of the design must be symmetric in both sides.



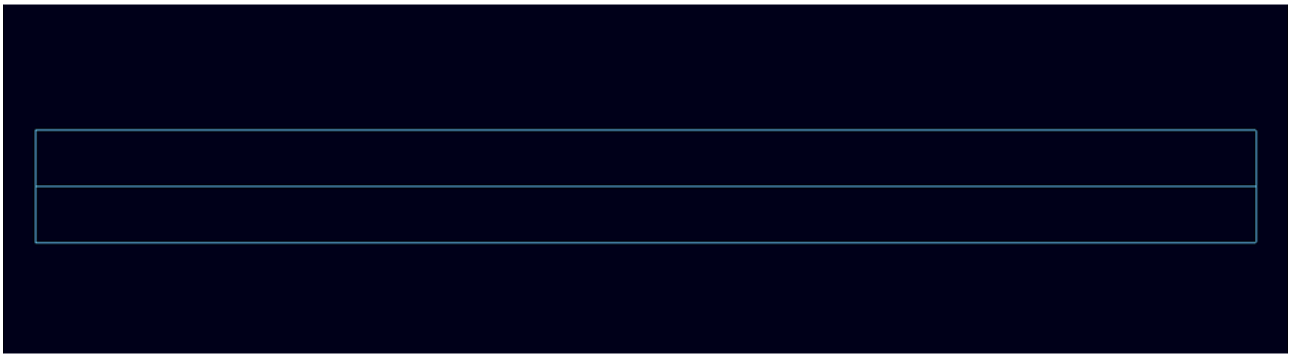
Picture 32. Left Side view

- Right side: Here it will show the right side of the car body, as it told in the picture before, it is the same than the left side.



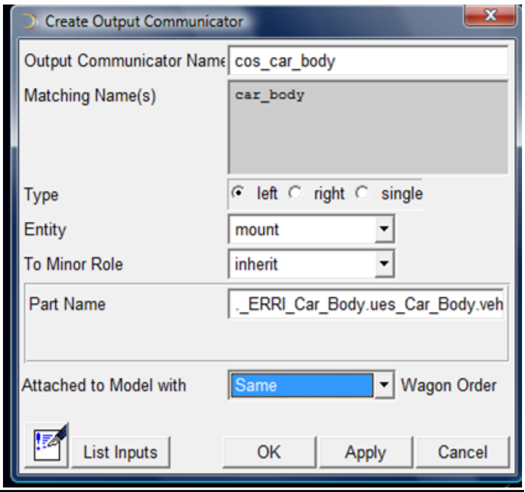
Picture 33. Right Side view

- Plant: In the plant view, just it is possible to see the roof of the railway.



Picture 34. Plant view

To create the output communicator it will fill the following dialog box how it is possible to see:



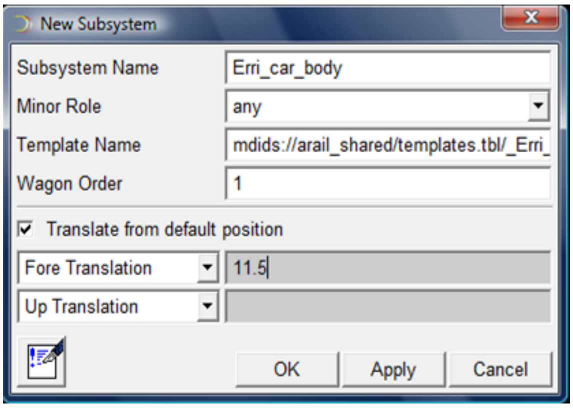
Picture 35. Dialog Box to create the Output Communicator

4.4. CREATING A BODY SUBSYSTEM

In this section, it will start the ADAMS/Rail Standard Interface in the UNIX and the Windows environments.

It will create the front running gear subsystem based on the *Erri Carbody* design stored in the standard template named *_Erri_Bogie.tpl*, and then save it.

To make the body subsystem it select File menu, point to New, and then select Subsystem, then The New Subsystem dialog box appears:



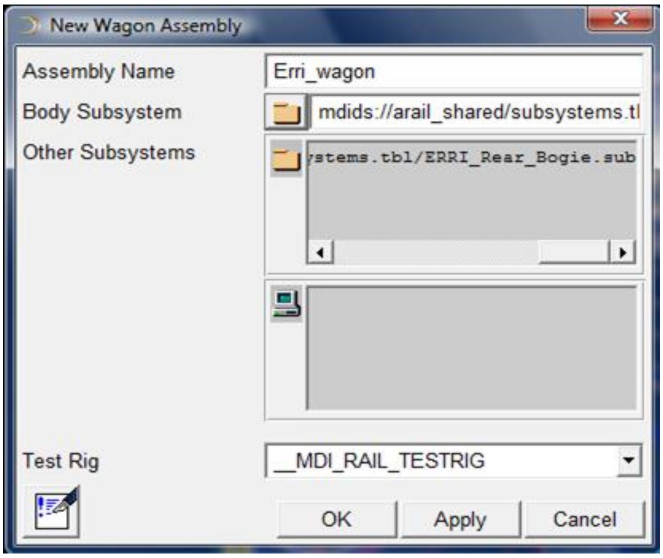
Picture 36. Dialog Box of the New Subsystem

4.5. CREATING A FULL-VEHICLE ASSEMBLY

In this section, it is possible to create a full rail-vehicle assembly. Using ADAMS/Rail, it can group separate subsystems into an assembly. This grouping simplifies the opening and saving of subsystems. It builds a full rail-vehicle assembly which contains the following:

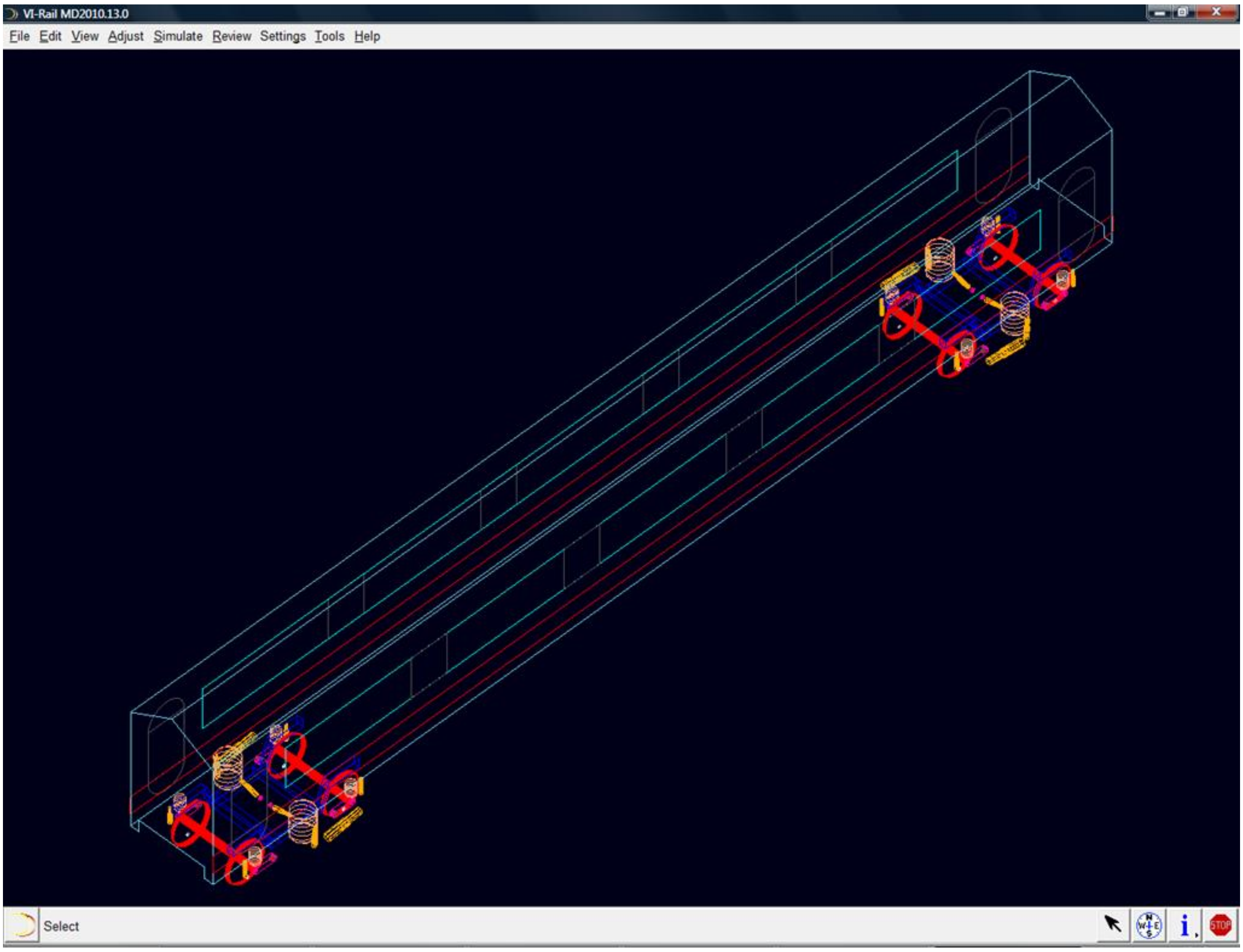
- Front and rear bogies
- Car body

To generate a full rail-vehicle assembly: from the File menu, point to New, and then select Wagon Assembly, then The New Wagon Assembly dialog box appears and it will fill how it shown below:



Picture 37. Dialog Box of the New Wagon Assembly

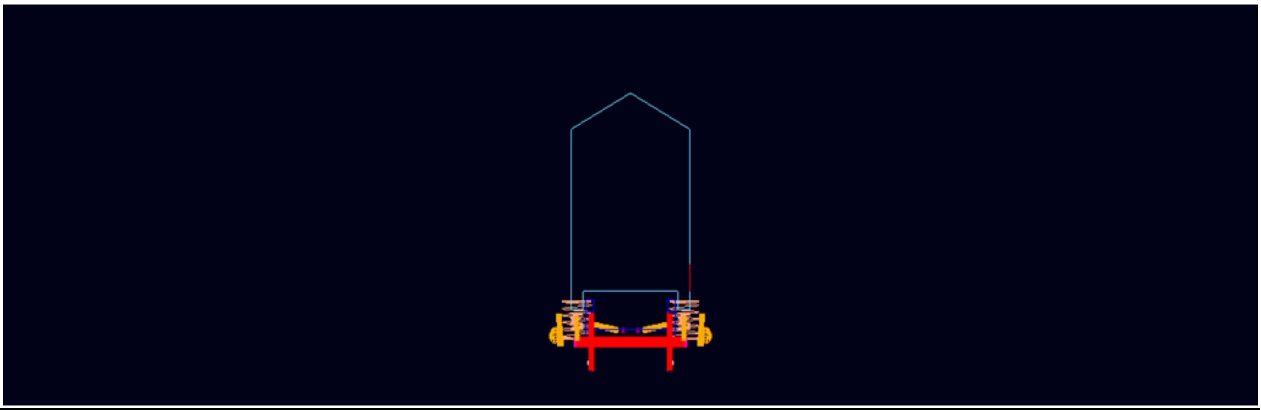
Finally, it can be seen the full vehicle assembly below. This sight is isometric view, with this view it is possible to see every element of the wagon created, both bogies (front and rear) and the car body. Also it can be shown the assembly done.



Picture 38. Full Vehicle Assembly

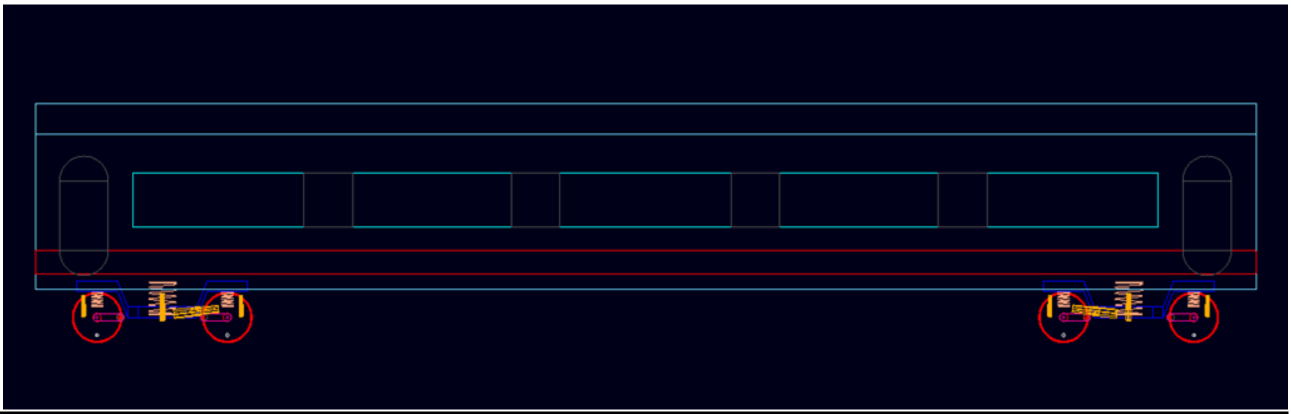
Following it can be seen the different views of the car body:

- Front: In this picture will show the front sight, it possible to see every element in their front side, the bogie and the car body. It can be seen that the wagon is symmetric.



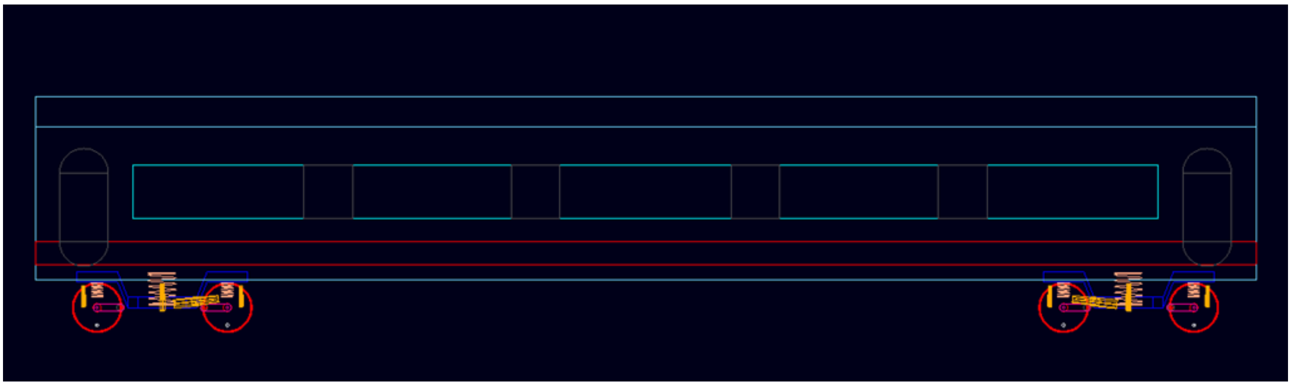
Picture 39. Front view

- Left Side: The next picture is the left side of the wagon, it will be the same that the right side, as is a railway, and this kind of the design must be symmetric in both sides. It possible to see both bogies assembly with the car body.



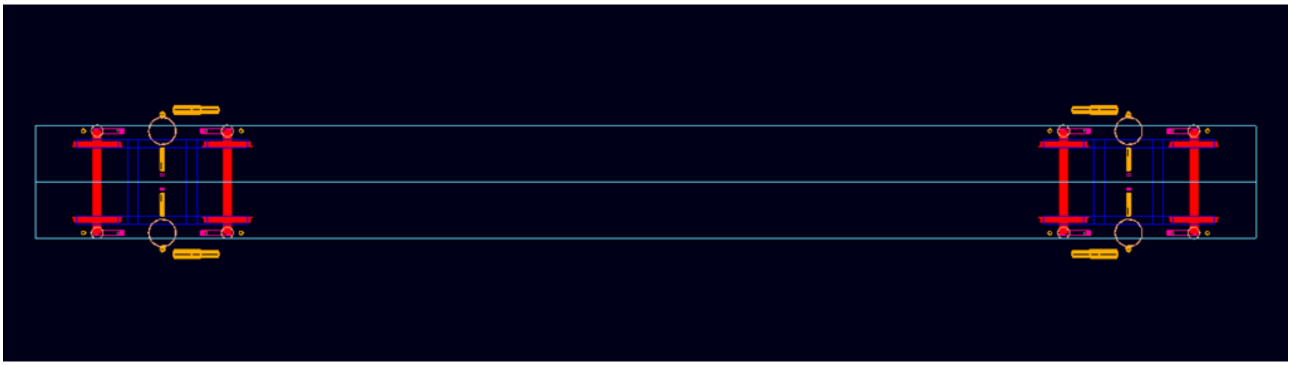
Picture 40. Left Side view

- Right Side: Here it will show the right side of wagon, as it told in the view previous, it is the same than the left side.



Picture 41. Right Side view

- Plant: In the plant view, it possible to see the roof of the car body and also the plant view of both bogies (front and rear).



Picture 42. Plant view

5. SIMULATION THE TEMPLATE

In this chapter reference [9] and [10] have been used.

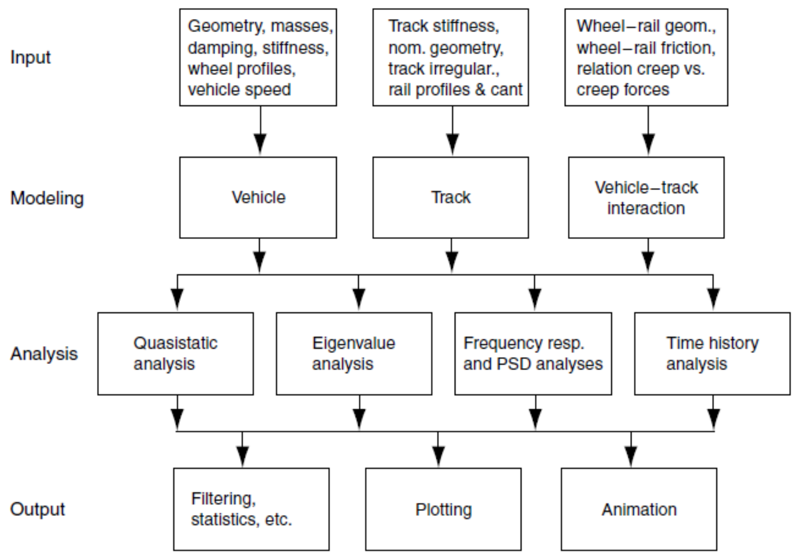
5.1. INTRODUCTION

With the advent of powerful computers simulation of complex mechanical systems has become a real possibility. A computer model of a railway vehicle can be constructed and run on typical or measured track in a virtual environment, and a wide range of possible designs or parameter changes can be investigated. Outputs from the model can be set up to provide accurate predictions of the dynamic behaviour of the vehicle and its interaction with the track. Optimisation of suspension or other parts of the system can be carried out, and levels of forces and accelerations can be checked against standards to ensure safe operation.

Inputs to the model are usually made at each wheelset. Typical inputs are vertical and lateral track irregularities and deviations in gauge and cross level. These can be idealised discrete events, such as dipped joints or switches, or can be measured values from a track recording coach.

Additional forces may be specified such as wind loading or from powered actuators.

The computer tools have developed from routines and programs used by researchers and engineers to solve specific problems, and the theoretical basis of the mathematical modelling used is now mature and reliable and programs originally written by research institutes have been developed into powerful, validated and user-friendly packages.



Picture 43. A flow chart showing the process of computer simulation of the railway system [10]

5.2. ANALYSIS

Once it creates the assembly model, ADAMS / Rail to analyze prototypes virtual as it be would used a physical prototype.

This simulation software can run a variety of analysis, where in necessary to specify:

- The name of the model.
- Data specific on the type of analysis desired.
- The additional property files that describe the information Admas / Rail needs to carry out the simulation, for example, file that defines the wheel / rail contact.

The main analyses that can be done with the program are:

- **Preload Analysis**: Used to understand the forces of preload on the vehicle suspension, therefore, often it used to check that the applied forces are equal to those obtained after the analysis run static.

- **Linear Analysis**: This analysis is used to calculate the eigenmodes of vibration of railway vehicle for this; the program restricts movement of wheels and wheels with respect to ground by fixed joints.

- **Stability Analysis**: It allows study the stability of the assembly, by analysis for different speeds and configurations of contact wheel-rail. This information can be used to determine the speed critical vehicle.

- **Dynamic Analysis**: It possible to use dynamic analysis to determine the curve behavior, the derailment, the study of comfort and stability.

Once the appropriate simulations, it is necessary to use a software, it is called ADAMS/Postprocessor, with this software it is possible to see the graphic representation as well as working with them.

5.3. PARAMETERS AND FACTORS USED

5.3.1. Some parameters to choose in simulation

- Conicity Value(s): In the working directory, ADAMS/Rail automatically generates a contact configuration file (CCF) that contains all the contact cases corresponding to the different conicity values you specified.

- Contact Configuration File - Specifies the contact parameters for the linearized wheel-rail component (the type must be the component based on quasi-linearized contact parameters.

- Initial Velocity: Specify the initial velocity.

- Velocity Increment: Specify the increment used to increase the velocity.

- Critical Damping: Specify the damping ratio threshold used to determine whether the current simulation corresponds to a stable or an unstable configuration.

- Frequency Range: Enter a frequency range. ADAMS/Rail evaluates only the modes within this frequency range with respect to the check of the damping ratio, to determine whether the actual analysis corresponds to stable or unstable configuration.

- Max Number of Analyses: Enter how many analyses it wants to run. (The default is 100.) After the number of analyses reaches this value, the stability analysis stops.

- End Time: Specify when it wants the analysis to end.

- Number of Steps: Specify the number of output steps for the analysis.

- DTOUT: Specify the dimension of the time interval for output steps

5.3.2. Parameters and Conditions for different kind of Analysis

A number of outputs were requested for each of the track cases, each of which was designed to test a particular potential vehicle problem. One of the most useful indicators of derailment potential is the lateral/vertical ($L=V$ or $Y=Q$) force ratio at each wheel.

In a curve it is usually the outer wheel where derailment takes place and. the peak value occurs at a dip designed to test vehicle suspension and shows that all five packages give good agreement on the nearness to derailment of the vehicle.

<u>TIPICAL CONDITIONS FOR LINEARISED BOGIE STABILITY ANALYSIS</u>: The next table shows the parameters input and the value recommended for Lienarised Bogie Stability Analysis.

Input Parameter	Recommended Value or Conditions
Wheel – rail contact geometry	Variation of equivalent conicity up to the maximum value expected in the service, representing various combinations of worn wheel and rail profiles as well as gauge variation.
Wheel – rail creep-force law	Full creep coefficients of Kalker’ s linear theory (dry rail).
Vehicle state	1. Intact 2. Failure mode: failure or reduced effect of yaw dampers
Vehicle loading	1. Tare (empty) 2. Full (crush) load
Vehicle speed	Speed variation from low up to high speed, in minimum up to the maximum test speed (usually maximum service speed + 10%)

Chart 6. Tipical Conditions for Linearised Bogie Stability Analysis [10]

TIPICAL CONDITIONS FOR LINEARISED CARBODY STABILITY ANALYSIS:

Following table is possible to see the parameters input and the value recommended for Lienarised Carbody Stability Analysis.

Input Parameter	Recommended Value or Conditions
Wheel – rail contact geometry	Low equivalent conicity (, 0.1).
Wheel – rail creep-force law	1. Full creep coefficients of Kalkers linear theory (dry rail) 2. Reduced creep coefficients of Kalkers linear theory, reduction factor 0.2 – 0.6 (wet rail)
Vehicle state	Intact
Vehicle loading	Tare (empty)
Vehicle speed	Speed variation between very low speed and maximum service speed

Chart 7. Tipical Conditions for Linearised Carbody Stability Analysis [10]

TYPICAL CONDITIONS FOR SIMULATION OF RIDE CHARACTERISTICS AND COMFORT: The next table can be shown the parameters input and the value recommended for Simulation of Ride Characteristics and Comfort.

Input Parameter	Recommended Value or Conditions
Track design	Straight track, curves with typical radius; optional comfort analysis in curve transitions (tilting trains)
Track irregularity	According to the specification and conditions on the railway network; measured track irregularity if possible
Wheel – rail contact geometry	Nominal profiles of wheel and rail, nominal gauge; sensitivity analysis of gauge narrowing and widening, analysis of influence of worn wheel and rail profiles
Wheel – rail creep-force law	Nonlinear theory, friction coefficient 0.4 (dry rail); analysis of influence of reduced friction coefficient 0.1 to 0.3 (wet rail)
Vehicle state	1. Intact 2. Failure mode: airsprings deflated (for ride characteristics only)
Vehicle loading	Tare (empty)
Vehicle speed for ride characteristics analysis	Maximum test speed (usually maximum service speed + 10%)
Vehicle speed for ride comfort analysis	1. Maximum service speed 2. Speed of carbody pitch and bounce resonance

Chart 8. Typical Conditions for Simulation of Ride Characteristics and Comfort [10]

<u>TYPICAL CONDITIONS FOR SIMULATIONS OF CURVING</u>: The table below shows the parameters input and the value recommended for Simulations of Curvings.

Input Parameter	Recommended Value or Conditions
Track design	1. Typical curve radii including transitions 2. The smallest curve radius on the network (outside of depot area)
Track irregularity	According to the specification and conditions on the railway network; measured track irregularity if possible
Wheel – rail contact geometry	Nominal wheel and rail profiles, nominal gauge, gauge widening in tight curves according to the specification; influence analysis of worn wheel and rail profiles, mainly for self-steering wheelsets
Wheel – rail creep-force law	Nonlinear theory, friction coefficient 0.4 (dry rail)
Vehicle state	Intact
Vehicle loading	1. Full (crush) load 2.Tare (empty); relevant for derailment safety investigation
Vehicle speed	Speed variation in function of curve radius and cant deficiency

Chart 9. Typical Conditions for Simulations of Curving [10]

6. RESULTS

6.1. INTRODUCTION

In this chapter, it will be shown the results obtain once done the simulations.

It will analysis every simulations separately, first of all, Preload and Linear Analysis where it will indicate if the system is stable or instable, after that, with the Stability Analysis it will be able to know the critical velocity and the natural frequency. And finally, it will complete with the Dynamic Analysis, in this analysis it possible to check the velocity, angular velocity, force, displacements, irregularities...

In this chapter just it will show the results, and in the chapter 7, these results will be examination and it will pronounce the conclusions.

This chapter has been written with the help of reference [7], [8], [9] and [10].

6.2. PRELOAD ANALYSIS

Through the analysis of preload is found that both the assembly operation as the definition of the properties of the components have been carried out successfully.

Adams / Rail preload forces calculated by the mass distribution applied the model and, once learned, applied directly to each element of the suspension. When the program applies the respective preloads, it may happen that the symmetry of model disappears. This event may be a bad deal for the masses, causing that elements of the suspension are more loaded than others, giving rise to it referred to as asymmetry.

From an analysis of preload, it possible to find that the model is perfectly constructed, all items maintain symmetry, as it possible to see below, something to take into account when making the rest of analysis.

```
$------------------------------------------------------------SUSPENSION_ELEMENT
[SUSPENSION_ELEMENT]
 N_SUSPENSION_ELEMENTS = 12
 SUSPENSION_ELEMENT_1 = '.ERRI_Wagon.ERRI_Front_Bogie.uer_front_PS'
 T_PRELOAD_Z_1 = 48691.8
 SUSPENSION_ELEMENT_2 = '.ERRI_Wagon.ERRI_Front_Bogie.uel_front_PS'
 T_PRELOAD_Z_2 = 44769.4
 SUSPENSION_ELEMENT_3 = '.ERRI_Wagon.ERRI_Front_Bogie.uer_rear_PS'
 T_PRELOAD_Z_3 = 48691.8
 SUSPENSION_ELEMENT_4 = '.ERRI_Wagon.ERRI_Front_Bogie.uel_rear_PS'
 T_PRELOAD_Z_4 = 44769.4
 SUSPENSION_ELEMENT_5 = '.ERRI_Wagon.ERRI_Front_Bogie.uer_SS'
 T_PRELOAD_Z_5 = 84021.9
 SUSPENSION_ELEMENT_6 = '.ERRI_Wagon.ERRI_Front_Bogie.uel_SS'
 T_PRELOAD_Z_6 = 76177.11
 SUSPENSION_ELEMENT_7 = '.ERRI_Wagon.ERRI_Rear_Bogie.uer_front_PS'
 T_PRELOAD_Z_7 = 47040.26
 SUSPENSION_ELEMENT_8 = '.ERRI_Wagon.ERRI_Rear_Bogie.uel_front_PS'
 T_PRELOAD_Z_8 = 43117.87
 SUSPENSION_ELEMENT_9 = '.ERRI_Wagon.ERRI_Rear_Bogie.uer_rear_PS'
 T_PRELOAD_Z_9 = 47040.26
 SUSPENSION_ELEMENT_10 = '.ERRI_Wagon.ERRI_Rear_Bogie.uel_rear_PS'
 T_PRELOAD_Z_10 = 43117.87
 SUSPENSION_ELEMENT_11 = '.ERRI_Wagon.ERRI_Rear_Bogie.uer_SS'
 T_PRELOAD_Z_11 = 80718.83
 SUSPENSION_ELEMENT_12 = '.ERRI_Wagon.ERRI_Rear_Bogie.uel_SS'
 T_PRELOAD_Z_12 = 72874.03
```

Chart 10. Numerical Results of Preload Analysis

```
$-----------------------------------------------------------------------BUSHING
[BUSHING]
N_BUSHINGS = 8
BUSHING_TPRELOAD = 'off'
BUSHING_1 = '.ERRI_Wagon.ERRI_Front_Bogie.bgr_rear_trail_bush'
T_PRELOAD_X_1 = 0.0
T_PRELOAD_Y_1 = 270.18
T_PRELOAD_Z_1 = 0.0
BUSHING_2 = '.ERRI_Wagon.ERRI_Front_Bogie.bgl_rear_trail_bush'
T_PRELOAD_X_2 = 0.0
T_PRELOAD_Y_2 = -270.18
T_PRELOAD_Z_2 = 0.0
BUSHING_3 = '.ERRI_Wagon.ERRI_Front_Bogie.bgr_front_trail_bush'
T_PRELOAD_X_3 = 0.0
T_PRELOAD_Y_3 = 270.18
T_PRELOAD_Z_3 = -0.01
BUSHING_4 = '.ERRI_Wagon.ERRI_Front_Bogie.bgl_front_trail_bush'
T_PRELOAD_X_4 = 0.0
T_PRELOAD_Y_4 = -270.18
T_PRELOAD_Z_4 = 0.0
BUSHING_5 = '.ERRI_Wagon.ERRI_Rear_Bogie.bgr_rear_trail_bush'
T_PRELOAD_X_5 = -0.03
T_PRELOAD_Y_5 = 270.18
T_PRELOAD_Z_5 = 0.01
BUSHING_6 = '.ERRI_Wagon.ERRI_Rear_Bogie.bgl_rear_trail_bush'
T_PRELOAD_X_6 = 0.01
T_PRELOAD_Y_6 = -270.18
T_PRELOAD_Z_6 = -0.01
BUSHING_7 = '.ERRI_Wagon.ERRI_Rear_Bogie.bgr_front_trail_bush'
T_PRELOAD_X_7 = 0.02
T_PRELOAD_Y_7 = 270.18
T_PRELOAD_Z_7 = -0.01
BUSHING_8 = '.ERRI_Wagon.ERRI_Rear_Bogie.bgl_front_trail_bush'
T_PRELOAD_X_8 = 0.0
T_PRELOAD_Y_8 = -270.18
T_PRELOAD_Z_8 = 0.01
```

Chart 11. Numerical Results of Preload Analysis

6.3. LINEAR ANALYSIS

The program ADAMS / Rail allows a linear analysis of vehicle modelling. This analysis is desirable linear analysis before to nonlinear analysis. This is why it allows for modal analysis model of the car, or whatever it will get the eigenvalues, the modes of vibration of the system and the frequencies at which they occur.

In general, the equations defining the dynamic response of the system are not remarkably linear, although a linear analysis will characterize the behavior of system. The causes of non-linearity in the dynamic analysis of railway vehicles are very different, but the most important are the following:

- Large relative displacements between different components produced vehicle.
- Non-linear behaviour of certain components of the suspension.
- Wheel-rail contact.

In a very general, vehicle dynamic equations can be expressed as follows:

$$f(X, X', X'') = U(t)$$

In this expression the first term is a force vector that depends on displacements, velocities and accelerations associated with the degrees of freedom vehicle and U (t) is the vector of external excitations. External Excitations may be due to external forces, uneven of the terrain, or address entries path to be followed due to the rails.

It will consider small displacements about an equilibrium position and Taylor series expansion to first order, the above equation becomes:

$$f\left(X_{0,}X_0', X_0''\right) + \frac{\partial f}{\partial X}\Delta X + \frac{\partial f}{\partial X'}\Delta X' + \frac{\partial f}{\partial X''}\Delta X'' = U_0 + \Delta U(t)$$

where (X_0, X_0’, X_0'', U_0) is the equilibrium position. As the reference position is equilibrium position, the above equation reduces to:

$$\frac{\partial f}{\partial X}\Delta X + \frac{\partial f}{\partial X'}\Delta X' + \frac{\partial f}{\partial X''}\Delta X'' = \Delta U(t)$$

If:

$$x = \Delta X$$

$$u = \Delta U$$

$$K = \frac{\partial f}{\partial X}$$

$$C = \frac{\partial f}{\partial X'}$$

$$M = \frac{\partial f}{\partial X''}$$

The expression is transformed to the linearized equation of movement:

$$[M] \cdot \{x''\} + [C] \cdot \{x'\} + [K] \cdot \{x\} = \{u(t)\}$$

Where [] are matrix and {} are vectors.

The mass matrices [M], stiffness [K] and damping [C] may be obtained by derivation of the force vector for nonlinear equations starting.

Once the equations are decoupled, one can solve the "n" equations of the system independently with the initial conditions of the system, for instance, it will become a problem of "n" degrees of freedom to "n" problems of one degree of freedom.

To obtain the new basis of the matrices formed by eigenvectors of the system damped, which is done is to calculate the eigenvectors and eigenvalues of the equation linearized of the movement for a damped free vibration. This equation is following:

$$[M] \cdot \{x''\} + [C] \cdot \{x'\} + [K] \cdot \{x\} = 0$$

It will be defined:

$$\{y\} = \left\{\frac{\{x'\}}{\{x\}}\right\}$$

And using:

$$[M] \cdot \{x'\} - [M] \cdot \{x'\} = 0$$

It will obtain:

$$\begin{bmatrix} [0] & [M] \\ [M] & [C] \end{bmatrix} \cdot \begin{Bmatrix} \{x''\} \\ \{x'\} \end{Bmatrix} + \begin{bmatrix} -[M] & [0] \\ [0] & [k] \end{bmatrix} \cdot \begin{Bmatrix} \{x'\} \\ \{x\} \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ \{0\} \end{Bmatrix}$$

It possible to write:

$$[A] \cdot \{y'\} + [B] \cdot \{y\} = \{0\}$$

The equation before is the same that:

$$\{y'\} - [H] \cdot \{y\} = \{0\}$$

Where:

$$[H] = -[A]^{-1} \cdot [B]$$

The solution of the equation will be:

$$\{y\} = \{\varphi\} \cdot e^{\gamma \cdot t}$$

where "γ" is a complex number and {Ψ} is the modal vector with complex elements. If it operate with the equation it possible to find another equation:

$$|\gamma \cdot [I] - [H]| \cdot \{\varphi\} = \{0\}$$

Where [I] it is the identity matrix.

The characteristic equation of the system is:

$$|\gamma \cdot [I] - [H]| = \{0\}$$

The roots "γi" of the characteristic equation represent "2n" eigenvalues, which are complex conjugate. Substituting "γ_i" it is possible to obtain eigenvectors corresponding to each eigenvalue. These eigenvectors are complex conjugates.

When one or more of the eigenvalues are zero, the eigenvector associated with the eigenvalue zero corresponds to a mode of vibration of a rigid body. This means that the system can move as a rigid body without any deformation of the elastic elements

The modal matrix is given as follows:

$$[\varphi] = [\{\varphi_1\}, \{\varphi_2\}, \dots, \{\varphi_{2n}\}]$$

The obtained eigenvectors are orthogonal to each other and it holds that:

$$\{\varphi\}_r^t \cdot [A] \cdot \{\varphi\}_s = 0 \qquad r \neq s$$
$$\{\varphi\}_r^t \cdot [B] \cdot \{\varphi\}_s = 0 \qquad r \neq s$$

Then:

$$[\varphi]^t \cdot [A] \cdot [\varphi] = [A]'$$
$$[\varphi]^t \cdot [B] \cdot [\varphi] = [B]'$$

Where [A]' and [B]' are diagonal matrices,

How it can see, the equations of motion and its calculation is simple, the decoupled equations can be obtained from the eigenmodes of vibration. A mode of vibration occurs when all the moving parts system are oscillating in phase with the same frequency. This movement is associated a characteristic frequency "ωj". The movement can be expressed as follows:

$$x(t) = \sum_j C_j \cdot \{\varphi\}_j \cdot e^{i \cdot w \cdot t}$$

Where C_j is a constant,

ADAMS / Rail made the linear analysis using the command LINEAR / EINGESOL that linearized equations to calculate the eigenvalues. For this analysis, ADAMS / Rail temporarily restrict all axles and wheels on the vehicle model to the reference "ground" through fixed joints. Of this analysis are obtained eigenvalues, so that its imaginary part represents the behavior oscillatory mode of vibration and its real part represents the damping characteristic of that mode.

In the table below will show the eigenvalues obtained by performing linear analysis program ADAMS / Rail.

EIGEN VALUES (Time = 0.0)

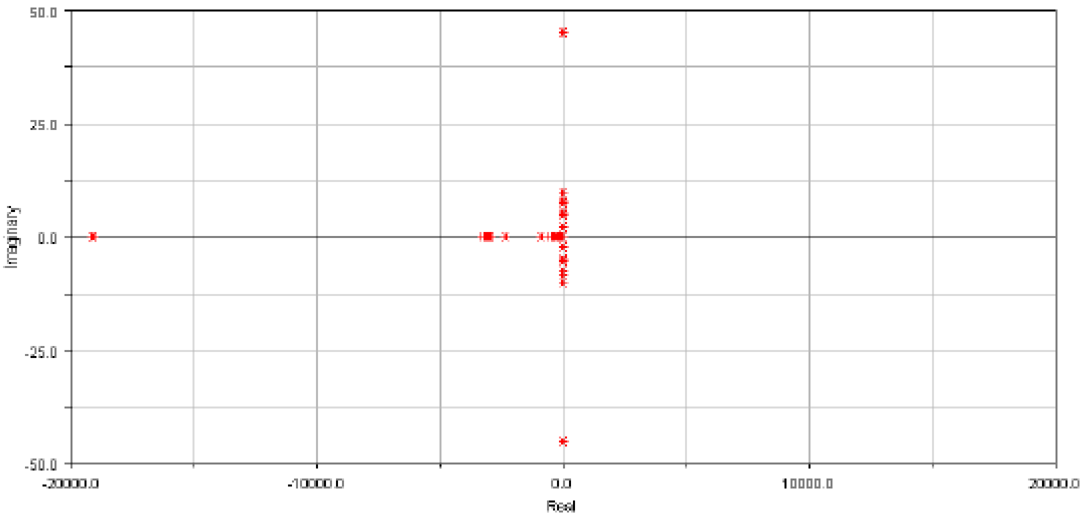
FREQUENCY UNITS: (Hz)

MODE NUMBER	UNDAMPED NATURAL FREQUENCY	DAMPING RATIO	REAL	IMAGINARY
1	5.569600E-010	1.000000E+000	5.569600E-010	0.000000E+000
2	1.515704E-001	1.000000E+000	-1.515704E-001	0.000000E+000
3	1.979752E+000	1.000000E+000	-1.979752E+000	0.000000E+000
4	2.526241E+000	1.000000E+000	-2.526241E+000	0.000000E+000
5	3.285425E+000	1.000000E+000	-3.285425E+000	0.000000E+000
6	3.431886E+000	1.000000E+000	-3.431886E+000	0.000000E+000
7	4.093699E+000	1.000000E+000	-4.093699E+000	0.000000E+000
8	1.518627E+001	1.000000E+000	-1.518627E+001	0.000000E+000
9	1.616081E+001	1.000000E+000	-1.616081E+001	0.000000E+000
10	1.629083E+001	1.000000E+000	-1.629083E+001	0.000000E+000
11	2.015935E+001	1.000000E+000	-2.015935E+001	0.000000E+000
12	2.367249E+001	1.000000E+000	-2.367249E+001	0.000000E+000
13	2.395474E+001	1.000000E+000	-2.395474E+001	0.000000E+000
14	2.845186E+001	1.000000E+000	-2.845186E+001	0.000000E+000
15	2.846255E+001	1.000000E+000	-2.846255E+001	0.000000E+000
16	3.382701E+001	1.000000E+000	-3.382701E+001	0.000000E+000
17	3.382930E+001	1.000000E+000	-3.382930E+001	0.000000E+000
18	3.649060E+001	1.000000E+000	-3.649060E+001	0.000000E+000
19	3.650137E+001	1.000000E+000	-3.650137E+001	0.000000E+000
20	3.679573E+001	1.000000E+000	-3.679573E+001	0.000000E+000
21	3.679853E+001	1.000000E+000	-3.679853E+001	0.000000E+000
22	3.804601E+001	1.000000E+000	-3.804601E+001	0.000000E+000
23	3.804602E+001	1.000000E+000	-3.804602E+001	0.000000E+000
24	5.182940E-001	2.702990E-001	-1.400944E-001	+/- 4.990012E-001
25	8.891971E-001	6.116563E-001	-5.438830E-001	+/- 7.034648E-001

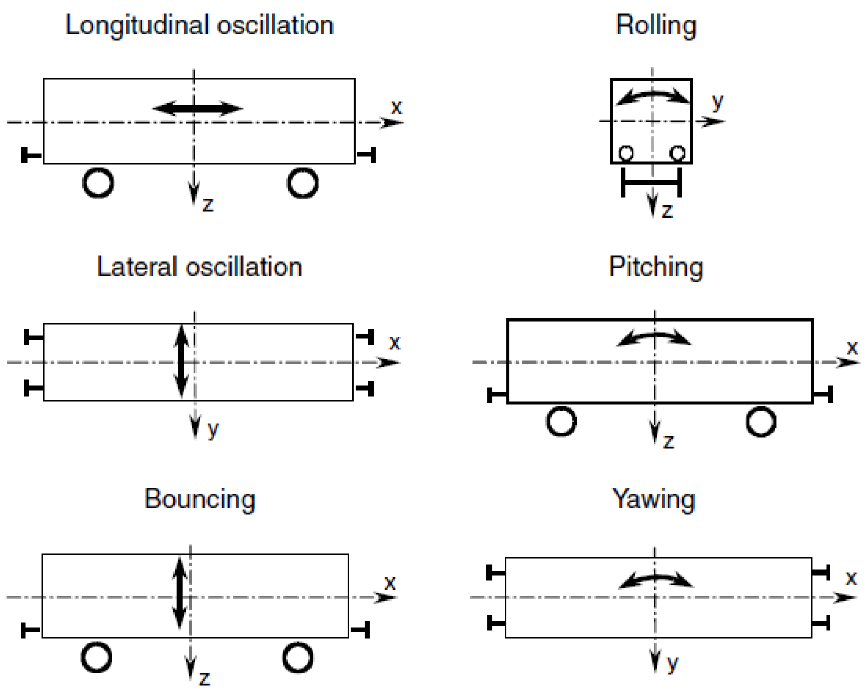
Chart 12. Numerical Results of Linear Analysis

26	1.260148E+000	4.787200E-001	-6.032579E-001	+/- 1.106369E+000
27	1.787733E+000	6.404509E-001	-1.144955E+000	+/- 1.372977E+000
28	1.745639E+000	5.384215E-001	-9.398896E-001	+/- 1.471007E+000
29	1.130833E+001	1.883304E-001	-2.129704E+000	+/- 1.110598E+001
30	1.132385E+001	1.878950E-001	-2.127695E+000	+/- 1.112216E+001
31	1.264981E+001	4.521559E-001	-5.719686E+000	+/- 1.128286E+001
32	1.301905E+001	4.515013E-001	-5.878117E+000	+/- 1.161651E+001
33	1.322851E+001	1.478189E-001	-1.955424E+000	+/- 1.308319E+001
34	1.329179E+001	1.487383E-001	-1.976998E+000	+/- 1.314394E+001
35	1.979070E+001	3.071496E-001	-6.078707E+000	+/- 1.883404E+001
36	2.033367E+001	3.033046E-001	-6.167295E+000	+/- 1.937583E+001
37	4.182993E+001	8.383494E-002	-3.506809E+000	+/- 4.168267E+001
38	4.204637E+001	8.927836E-002	-3.753831E+000	+/- 4.187847E+001
39	4.469398E+001	1.241101E-001	-5.546974E+000	+/- 4.434843E+001
40	4.469795E+001	1.241607E-001	-5.549730E+000	+/- 4.435208E+001
41	2.003353E+002	3.773051E-004	-7.558752E-002	+/- 2.003353E+002
42	2.003407E+002	3.772871E-004	-7.558597E-002	+/- 2.003407E+002
43	2.052181E+002	2.868080E-004	-5.885819E-002	+/- 2.052181E+002
44	2.052231E+002	2.867873E-004	-5.885540E-002	+/- 2.052231E+002
45	2.061974E+002	2.159410E-004	-4.452647E-002	+/- 2.061974E+002
46	2.062020E+002	2.159233E-004	-4.452383E-002	+/- 2.062020E+002
47	2.077507E+002	2.594882E-004	-5.390884E-002	+/- 2.077507E+002
48	2.077555E+002	2.594830E-004	-5.390904E-002	+/- 2.077555E+002

Chart 13. Numerical Results of Linear Analysis



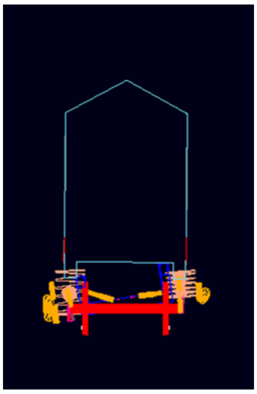
Graphic 1. Graphic Result of Linear Analysis



Picture 44. Basic Carbody Modes [10]

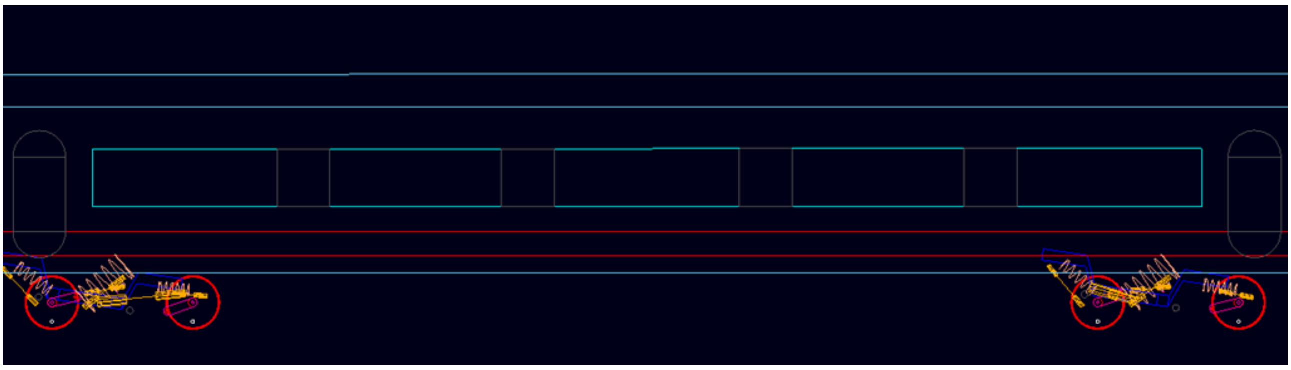
Following the pictures will be shown some modes of vibrations:

The next picture shows mode 36 of vibration in front view.



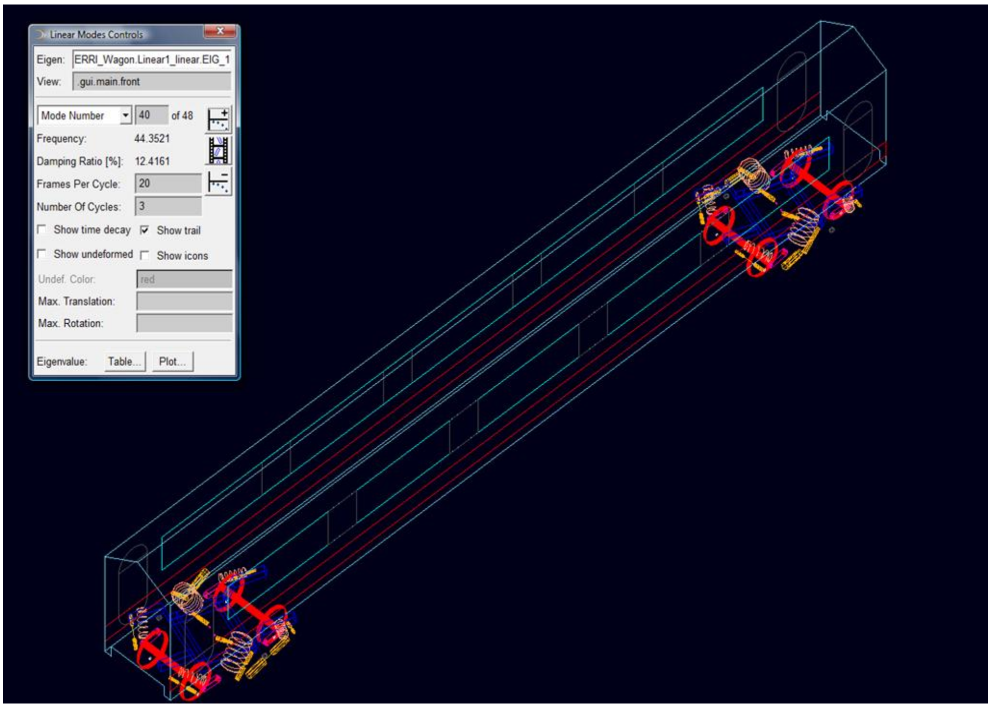
Picture 45. Mode 36 of Vibration

In the picture below is possible to appreciate mode 38 of vibration in left side:



Picture 46. Mode 38 of Vibration

It is possible to see in isometric view mode 40 of vibration; in this kind of view it can be seen the behavior of every element of the wagon.



Picture 47. Mode 40 of Vibration

6.4. STABILITY ANALYSIS

The study of the problem of stability is very important because through it know the limits of operation of the system studied. A system is unstable if it away from its equilibrium position not answer is damped and amplified in time. In the rail vehicle dynamic instability is characterized by the fact that above a certain speed of movement, any oscillation produced in the course of the vehicle tends to be amplified. This speed is known name of **critical velocity**.

When it goes a speed exceeding the critical speed up a system is sustained oscillations. These oscillations cause the wheel flanges collide violently with the inner faces of the rails leading to a decrease security during the march, an increase in requests from the wheels and rails, and a deterioration in track geometry and ride comfort of the vehicle. The movement in these conditions is unacceptable and, therefore, the dynamic instability limits the maximum speed at which a vehicle can travel.

The critical speed depends on several parameters, which include characteristics of the suspension, weight distribution, the surface of the lane, taper of the wheels, traction and braking effort. The existence of a speed critical in a vehicle can´t be avoided, although you can increase its value by the study of the model and the subsequent change in the required parameters.

To calculate the critical speed of movement it have to calculate the time when the system becomes unstable.

The linear analysis provided the eigenvalues and the modes of vibration of the system. It was found that the eigenvalues resulting from the linear analysis were complex conjugates. If the real part of them was positive, the vibration mode was unstable. In the analysis Stability is the damping coefficient used to define instability dynamics.

Sea "μ_i" the eigenvalue of the vibration mode "i ". As can be complex conjugate written as follows:

$$\mu_i = \alpha_i + j \cdot \beta_i$$

$$j = \sqrt{-1}$$

The natural frequency (ω_{ni}), damped frequency (ω_{di}) and the coefficient buffer (ξ_i) can be written in terms of the values of the eigenvalue:

$$\omega_{ni} = \sqrt{\alpha_i^2 + \beta_i^2}$$

$$\omega_{di} = |\beta_i|$$

$$\xi = \frac{-\alpha_i}{\sqrt{\alpha_i^2 + \beta_i^2}}$$

If the system is stable, the damping coefficient is positive, in others words, the real eigenvalue is negative. If the system is unstable, the real part of eigenvalue is positive. In this case, the vehicle is a divergent harmonic oscillation that occurs at a frequency "ω_{di}."

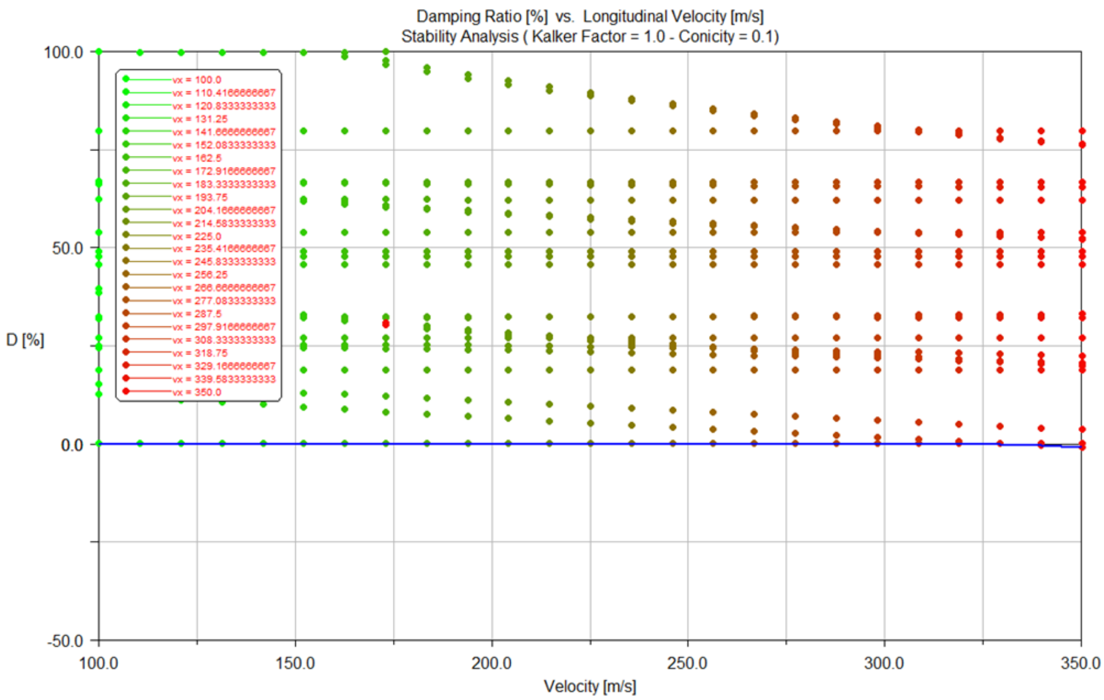
A normal mode of vibration occurs when the masses are oscillating system such thus reaching the maximum displacements at the same time and go through their equilibrium positions at a time, or when all the moving parts of the system are oscillating in phase with the same frequency.

To obtain a measure of damping of the main modes of vibration, damping coefficients are calculated in the range of operating speed the vehicle. The value of the smallest damping of vibration modes is used as a proxy measure to reflect not only stability but also damped response to a disturbance. The higher the value, it be damped mode of vibration.

Once the stability criterion will analyze the results obtained to perform stability analysis in ADAMS / Rail. For this we have chosen an interval speed between 100 m /s and 350 m / s.

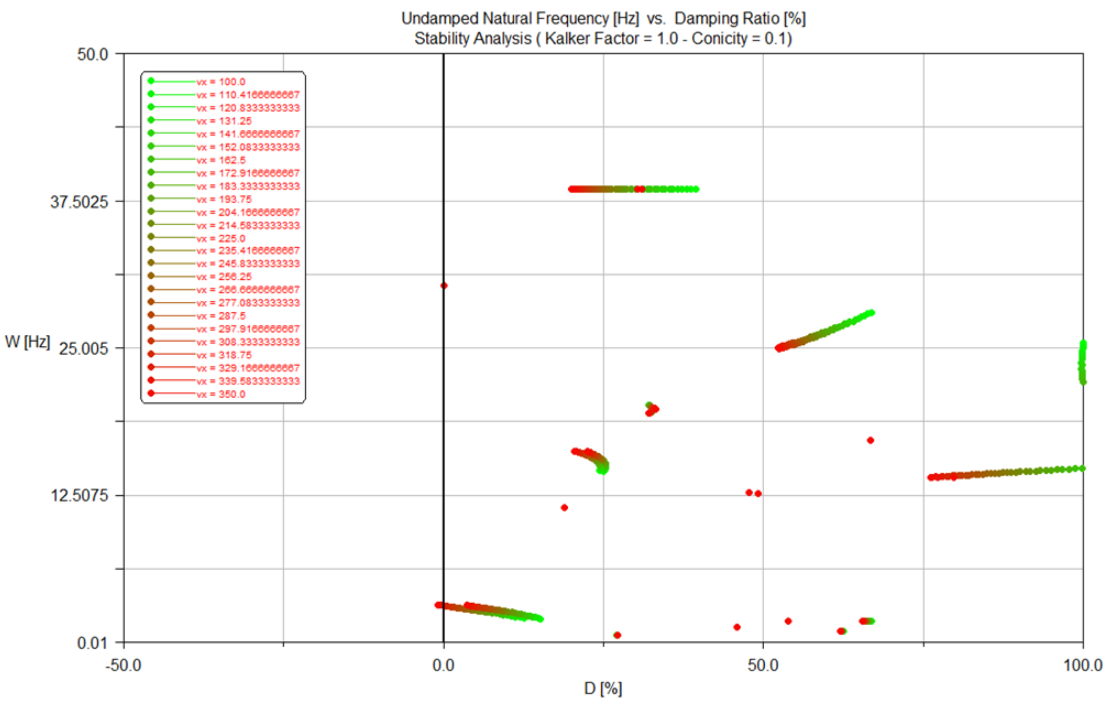
The number of tests performed in this interval analysis was 25, so that velocity range from analysis and analysis is 2 m / s. In this way we obtain an approximation for determining the critical speed of the model.

In the next graphic represents the values of damping ratio against the velocity have been obtained from the simulation:



Graphic 2. Damping Ratio vs Longitudinal Velocity

Once you have determined the critical speed is to see what it is the natural frequency:



Graphic 3. Undamped Natural Frequency vs Damping Ratio

6.5. DYMAMIC ANALYSIS

The potential and success of vehicle track dynamic simulations very depends on how well the system is mathematically modelled and fed with pertinent input data. The system modelling involves several fields of mechanics and, owing to its many complexities, is an engineering challenge. The choice of models for the system and its components depends on several aspects, mainly:

- Purpose of simulations, including requested output quantities and their accuracy
- Frequency range of interest
- Access to appropriate simulation packages
- Access to relevant model data
- Time and funding available

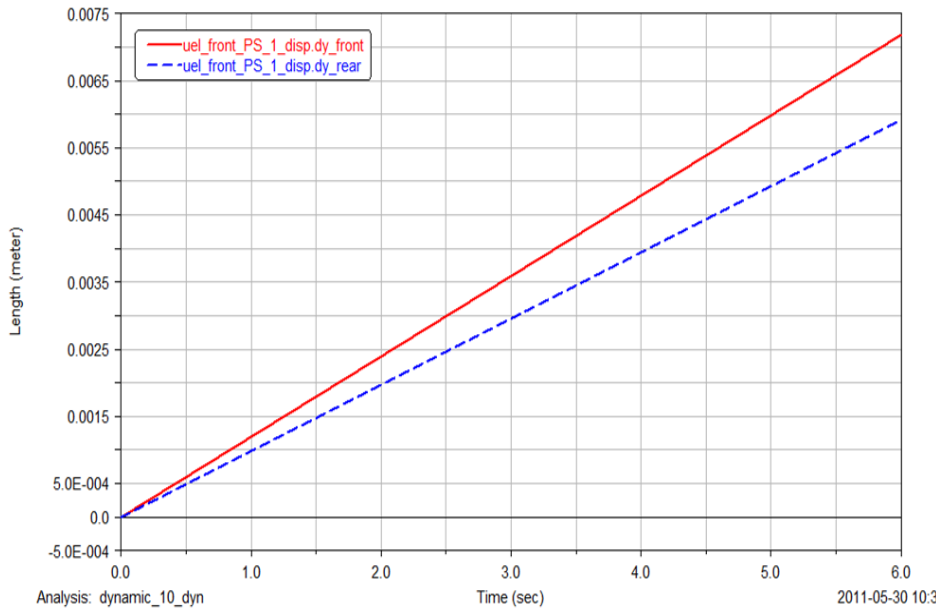
Finally, there are also restrictions on available staff-time, calendar-time, and economical resources, which in practices, constrain the modelling possibilities.

The art of modelling requires engineering experience and judgment. It also requires a significant amount of relevant and reliable technical information on the vehicle track system at hand.

Following it will be shown the results of the dynamic simulations; the initial velocity for this analysis was 10 m/s.

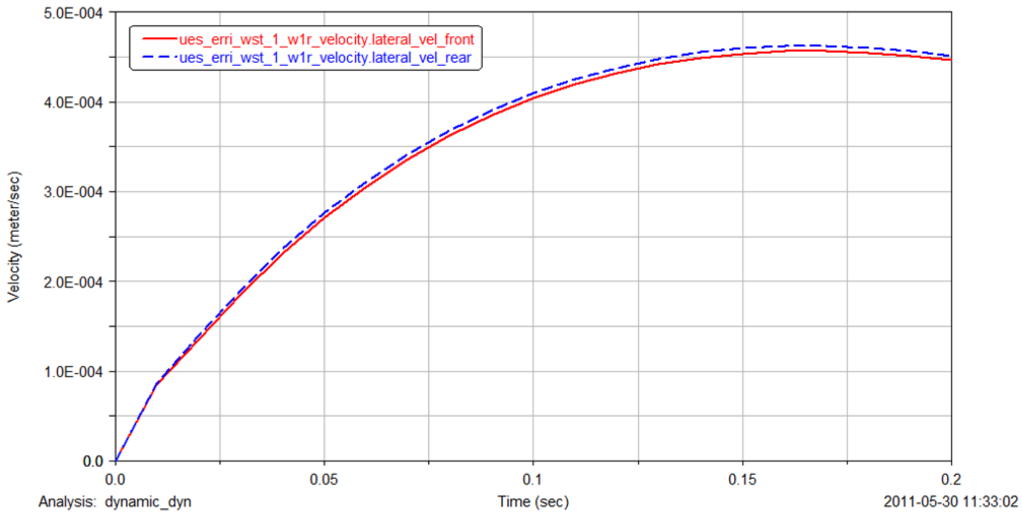
6.5.1. Straight

It possible to see that as time (seconds) increases so the length (meters) does linearly. As it shows the graphic, the bogies front and rear have the same behavior.



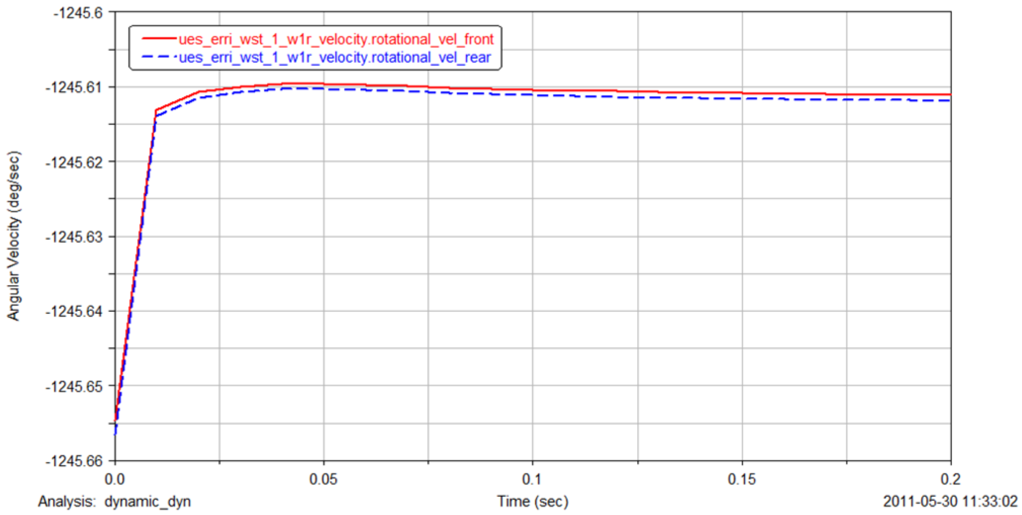
Graphic 4. Lenght vs Time

In the next graphic can be seen that the velocity grows with the time, later the velocity is stabilized. The same manner in both bogies



Graphic 5. Velocity vs Time

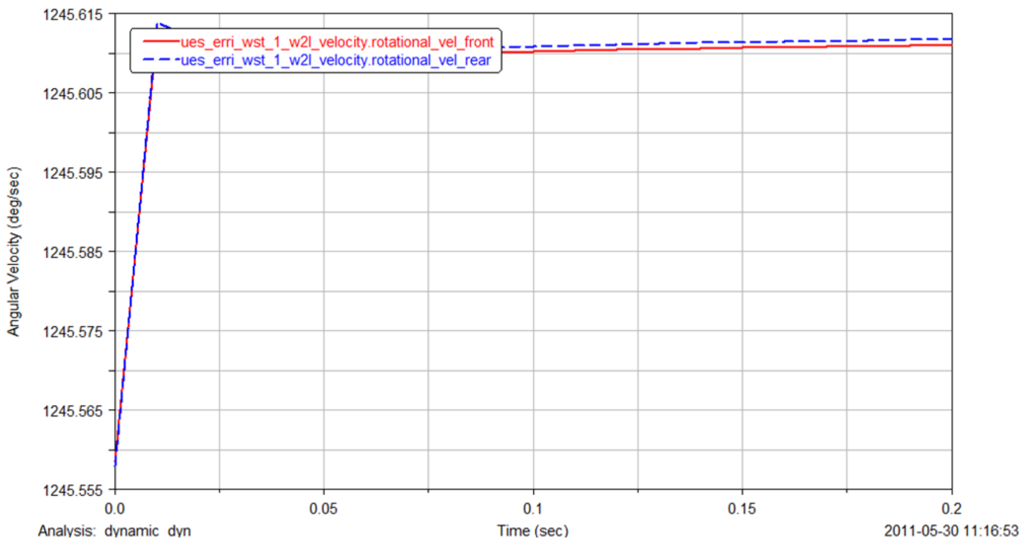
How is possible to see, the graphic shows a very fast growth of angular velocity in a few seconds stabilising later.



Graphic 6. Angular Velocity vs Time

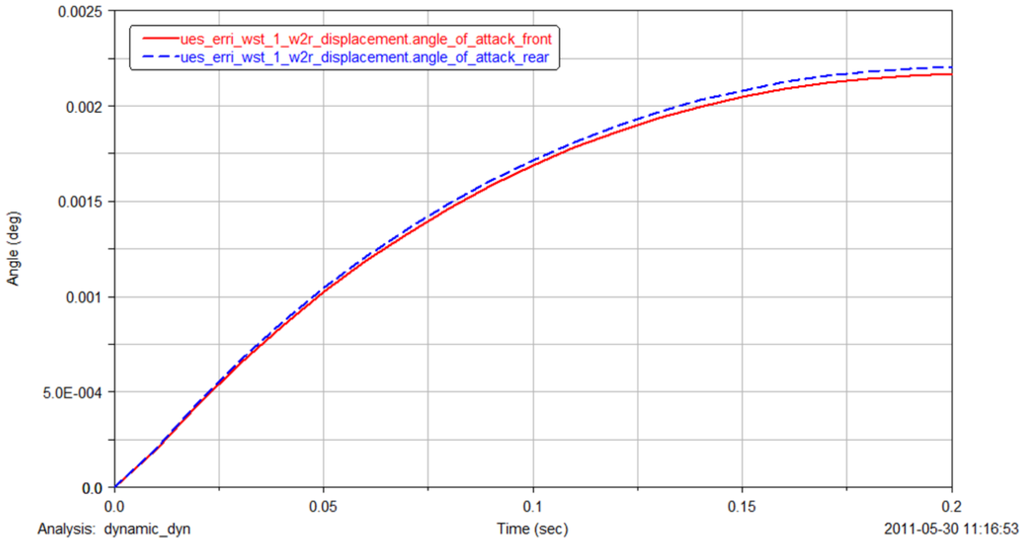
6.5.2. Curve

As it was said the straight analysis, the angular velocity growth very fast and later it is more or less stabilized.



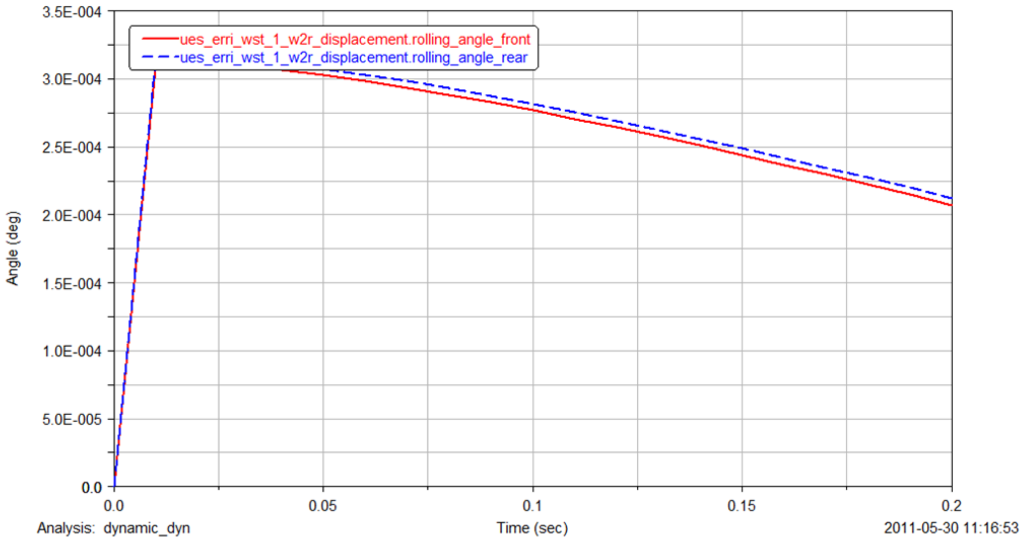
Graphic 7. Angular Velocity

Following, the graphic is shown that the displacement angle growth with the time. Both bogies have similar behavior.



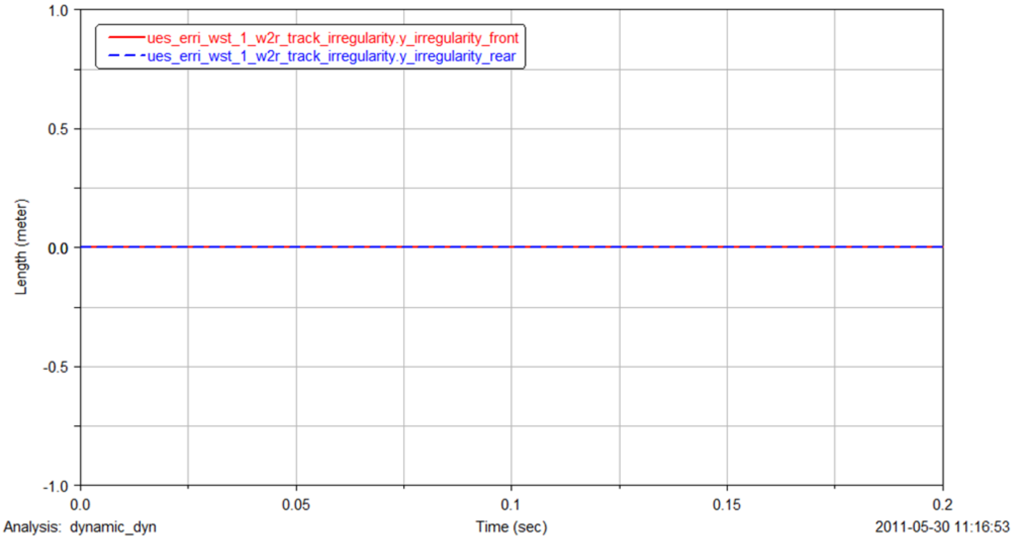
Graphic 8. Displacement Angle vs Time

The graphic shows the behavior of the displacement rolling angle versus time.

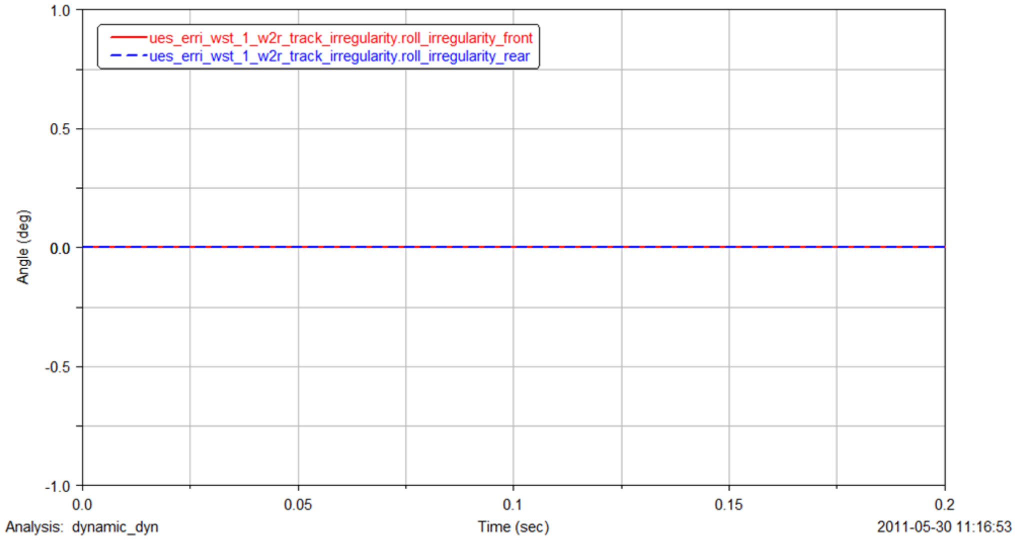


Graphic 9. Displacement Rolling Angle vs Time

Graphics 10 and 11 show that there are no irregularities.

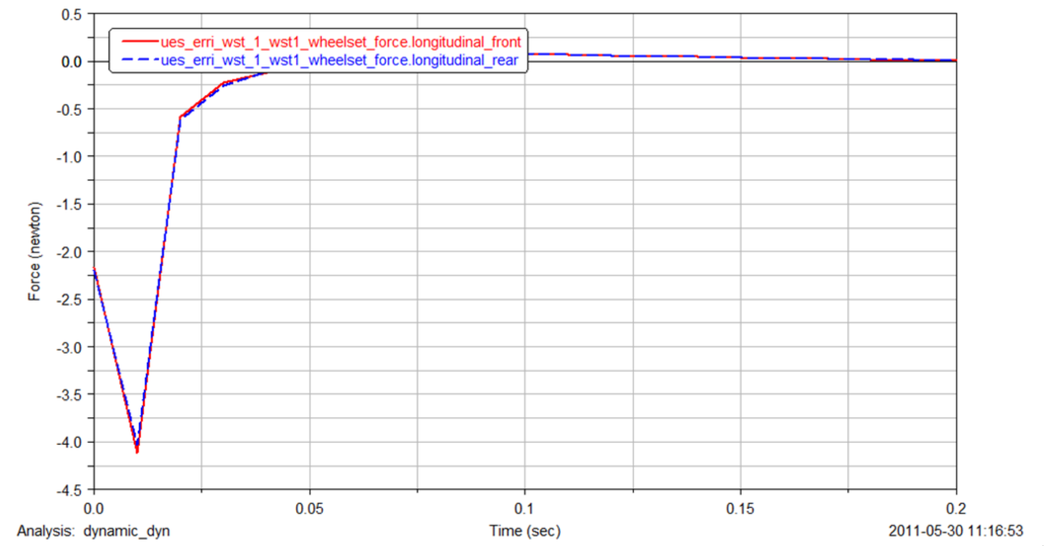


Graphic 10. Length vs Time



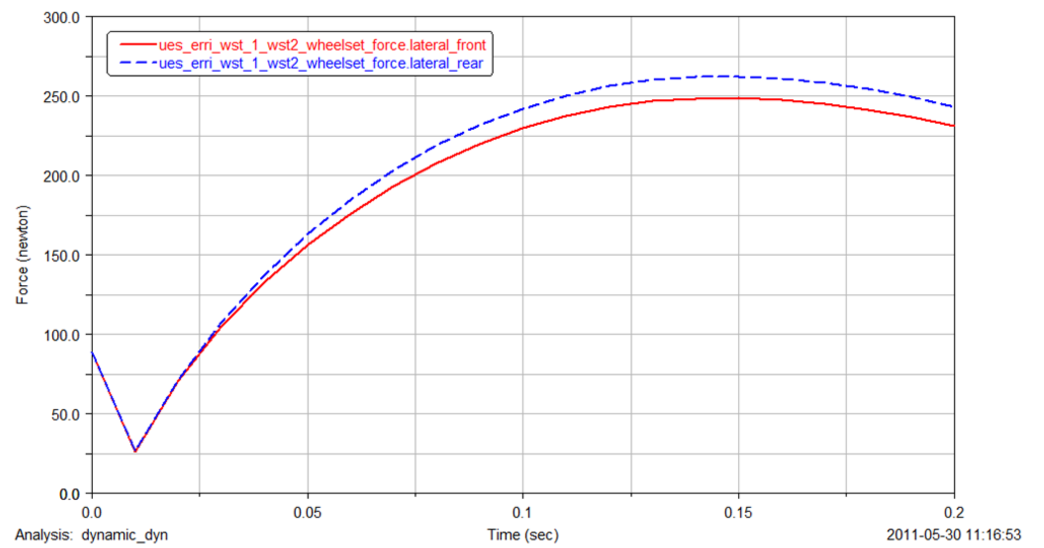
Graphic 11. Angle vs Time

How is possible to see in the graphic 13 the force longitudinal in wheels decreased and increased very fast in a few seconds and later this force is stabilized. The same behavior there is in both bogies.



Graphic 12. Force Longitudinal vs Time

The subsequently graphic shows the behavior of wheels lateral force versus time.



Graphic 13. Force Lateral vs Time

7. CONCLUSIONS

7.1. PRELOAD ANALYSIS

In view of the results, it can say that the masses are distributed symmetrically and therefore, the vehicle is symmetrical. This conclusion is useful if it want calculate something, it necessary to delete the effect of the asymmetry in obtaining the displacement.

7.2. LINEAR ANALYSIS

How is possible to see in the charts for this analysis, in the first column is found the mode number of vibration. The fourth contains the values of the real part associated with each eigenvalue, and the last column represents the imaginary part of the eigenvalues of the system.

The first 23 values correspond to rigid modes of vibration; it means that the vehicle is moving as a rigid body. The remaining modes correspond to eigenvalues own of vibration.

Unstable modes of vibration are those have positive real part of eigenvalue. In this case, do not get any with some positive real, so, they are all stable.

The frequency of lower sway mode should be higher than 0.5 Hz, otherwise there is a risk of motion sickness arising. The eigendamping of the carbody modes should be between 15 and 30%. This target value is usually difficult to achieve for all carbody eigenmodes. For lower influence mode values slightly below 15% are also acceptable. The damping of the carbody yaw and upper sway modes is usually higher than 30%, but this is not critical from a running behavior perspective.

7.3. STABILITY ANALYSIS

When the coefficient damping is less than zero, the system becomes unstable. The speed at which the blue line starts to have values of damping ratio less than critical velocity is zero. It possible to see in graphic 2 that the critical velocity is around 340 m/s.

The graphic 3 shows a zone that crosses the line of points vertical at the origin. These points correspond with a natural frequency approximately 3Hz, which instability occurs.

7.4. DYNAMIC ANALYSIS

In every graphic it possible to see that both bogies (front and rear) has the same behavior.

7.4.1. Straight

The analysis shows that the velocity and length grow with the time

However the angular velocity grows very fast in a few seconds and it is stabilized later.

7.4.2. Curve

The behavior of the angular velocity is similar to straight analysis, it grows very fast and later it is more or less stabilized.

It is possible check that the displacement angle growth with the time.

Displacement rolling angle in a few seconds grows very speedy, however, after this fact the displacement rolling angle is going to decrease.

It is important to say that it is possible to see in graphics 10 and 11 that there are no irregularities.

The force longitudinal in wheels decreased and increased very fast in a few seconds and later this force is stabilized.

The graphic of force lateral shows the behavior of wheels lateral force versus time. First it decreases, later, it grows and decreases again a little bit. It is important to say that as time passes there is a difference of force between front and rear bogies, the force of the rear bogie is bigger than the front one.

7.5. FINAL CONCLUSION

After Design, Simulation, Analysis (Preload, Linear, Stability and Dynamic), and study the results and once done every conclusion for each analysis it can summarize:

- In the Preload analysis is observed that the vehicle is symmetrically, something essential.
- Later, it made Linear Analysis; here it checked with enginevalues and mode of vibrations, that the vehicle is stable.
- After that, it prepared Stability Analysis, with this analysis it was calculated the critical velocity and the natural frequency (both values are very fine).
- And finally, the last analysis is the dynamic, in this analysis it was checked with graphics, the force, the displacement and other important parameters, every parameters studied are good.

Thus it is possible to conclude that the results are very good, it means that the railway designed has good quality at the same time as the parameters chosen.

8. SUMMARY

The purpose of this thesis has been the Railway Simulation and a study about it, with the help from the Analysis.

To can do the simulation desired it is necessary a railway, then it appeared a new goal: the design of this railway. This is why the title of this Master Thesis: *“Railway Design, Simulation and Analysis by ADAMS/ Rail Software”.*

In this Master Thesis has been used a software called ADAMS/ Rail; to create the design, to do the simulations and to study the analysis. This software is used for this kind of projects.

ADAMS/Rail is a specialized environment for modelling rail vehicles. It allows you to create virtual prototypes of rail vehicle, and analyze the virtual prototypes much like you would analyze the physical prototypes. Using ADAMS/Rail, It can quickly create assemblies of rail vehicles, and then analyze them to understand their performance and behaviour.

Following the Design, Simulation and Analysis done, it can say that the masses are distributed symmetrically therefore, the vehicle is symmetrical and the vehicle is stable. This conclusion is necessary.

In addition is possible to know that the critical velocity is around 340 m/s and the natural frequency is approximately 3Hz. These values are between expected range.

Also, it can be pronounced that both bogies (front and rear) have the same behavior and they have not irregularities. This aspect is very important in every Railway Design.

As well, concluding that the important parameters studied as Longitudinal and Angular Velocity, Displacement Angle and Rolling, Length and Force Longitudinal and Lateral have a good and correct performance.

Finally, it is good to remember the academic goal has been to learn how design a railway, to find out how to extract results and conclusions of simulations and lastly but not less important how ADAMS/Rail Software works.

9. FUTURE ANALYSIS

Computer analyses and simulations of vehicle dynamics constitute an integral part of engineering processes during the development and design of new and modified railway vehicles. Virtual prototyping computer tools have made considerable progress in recent years.

The simulation of railway vehicle system dynamics can be coupled with other simulations from structural mechanics, aerodynamics, controls, electrotechnics, etc. to a virtual development process. Modern simulation packages provide powerful and important analysis and design tools that are well-suited to the concurrent engineering process demands in the railway industry.

A good future analysis could be done about structural mechanics, aerodynamics, electric and electronic on this railway.

Moreover, another proposal is to do a more intense dynamic analysis to improve these railway parameters in order to make it more comfortable for the passengers.

It is also possible to do some analysis to decrease pollution.

10. REFERENCES

WEB SIDES:

[1]➔http://www.portalplanetasedna.com.ar/ferrocarril.htm

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