# RAIL COACH FACTORY (KAPURTHALA), INDIA

## 16th European Mechanical Dynamics Users' Conference

## Design Development of Meter Gauge Bogie

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*Rail Coach Factory is a leading manufacturer of railway coaches owned by Indian Railways. The factory has recently designed and developed a Meter Gauge bogie fit for 120 kmph operation. Broad Gauge 'Y' frame flexi-coil bogie was taken as a starting concept for this design.*

*A model of the proposed design was prepared in ADAMS/Rail and analyzed for various parameters such as Lateral and vertical forces acting on different parts of bogie, On-loading and Off-loading of wheel, conicities vs. displacement, limit of track shift forces (Prud'homme criteria), derailment coefficient and ride indices.*

*Based on results of these parameters, yaw dampers were eliminated and damping coefficients of other vertical and lateral dampers were fine-tuned. The critical speed of the vehicle has been found out within the frequency range of 0.1Hz to 10 Hz. The lateral and vertical ride indices were determined with vehicle running on straight track with velocities ranging from 40 km/h to 120 km/h on selected section of track irregularities.*

*The ADAMS/Rail analysis has, thus, considerably helped Rail Coach Factory to optimize suspension design of its Meter Gauge 'Y' frame flexi-coil type bogie.*

*The paper discusses stages in model preparation and inferences made from the simulation results.*

## 1. Introduction

Rail Coach Factory, Kapurthala is a leading manufacturer of railway coaches owned by Indian Railways. This factory uses UNIGRAPHICS software for Computer Aided Designing and ADAMS/Rail for vehicle dynamics analysis.

For upgrading rolling stock on meter gauge (1000 mm) of Indian Railways, RCF have recently designed and developed a Meter Gauge bogie fit for 110 kmph operation. This bogie is based on Eurofima concept running on standard gauge (1435 mm), which has been adapted for Meter Gauge. Objective of the vehicle dynamic analysis was to achieve a ride index of upto 2.75 (Sperling) at a maximum speed of 125 kmph. ADAMS/Rail version 9.1 was used for the analysis. Version 11.0 of this software has recently been installed.

The Meter Gauge 'Y' frame flexi-coil type bogie, designed at RCF, has a wheel base of 2.15 M. The attachment of axle box to bogie frame comprises of a control arm that provides lateral and longitudinal articulation of the axle box. Further, axle box is also connected to bogie frame through helical coil spring nest (primary springs).

The car-body is connected to the bogie frame by traction linkage and secondary suspension flexi-coil springs on which it is directly carried. This permits rotation and transverse movement between the car body and bogie. Since a soft secondary suspension was chosen for better riding, an anti-roll bar has been provided to control the rolling of the coach.. The car-body is free to oscillate on the flexi-coil suspension within permitted clearances. The bogie is shown in Figure-1 below.

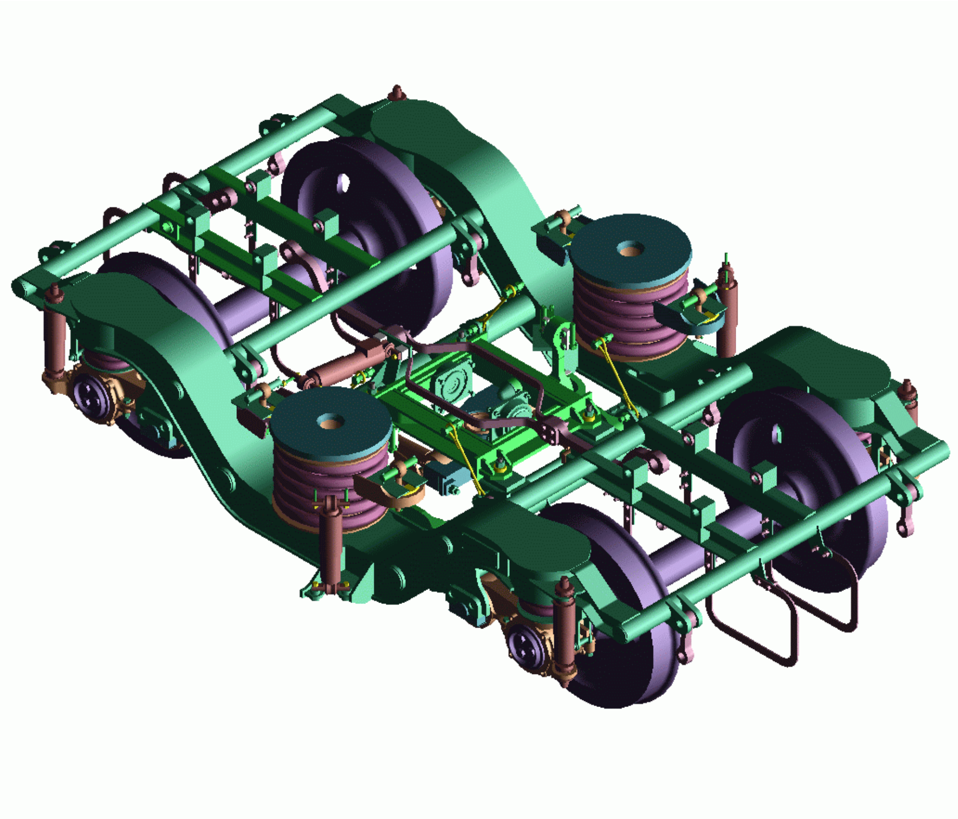

***Figure-1*** *Shaded view of Meter Gauge 'Y' frame flexi-coil type bogie in UG*

Two options were tried, one with yaw damper and the other without yaw damper. The option without yaw damper was found to be suitable for our requirements.

The critical speed of the vehicle has been established at 210 kmph without yaw damper for the frequency range of 0.1Hz to 10 Hz. The lateral and vertical ride indices were determined with vehicle running on straight track with velocities ranging from 40 km/h to 125 km/h on selected section of track irregularities.

## 2. MODELLING

### 2.1 MODELLING ASSUMPTIONS

The assumptions made in formulating the vehicle model in ADAMS/Rail are as follows:

- The bogie and the car-body component masses are rigid and their flexibility is lumped in the suspension.
- The vehicle is loaded symmetrically with respect to lateral and longitudinal vertical planes through the geometric center of the vehicle.
- The springs and the dampers of the suspension system elements have linear characteristics.
- Bogie bolster is assumed as car body's integral part, hence weight of the transverse beam is combined with the car body.
- Friction does not exist between axle and bearings.
- The vehicle is moving at constant velocity on rigid and constant gauge.
- All wheel profiles are identical from left to right on a given axle and from axle to axle and all wheels remain in contact with the rails.
- Conicity is dependent on lateral displacement of the wheel sets and flanging does not occur.
- Straight track was assumed.

## 2.2 Model preparation in ADAMS/Rail

As a first step of model preparation, one model of Meter Gauge 'Y' frame flexi-coil type bogie was assembled. A group of the entire components, links, joints and suspension element was made and copied at the center pivot distance to build the second bogie. The complete vehicle model is composed of fifteen rigid bodies. The entire model has 26 degrees of freedom. Figure-2 below depicts the rendered ADAMS/Rail Model of the bogie.

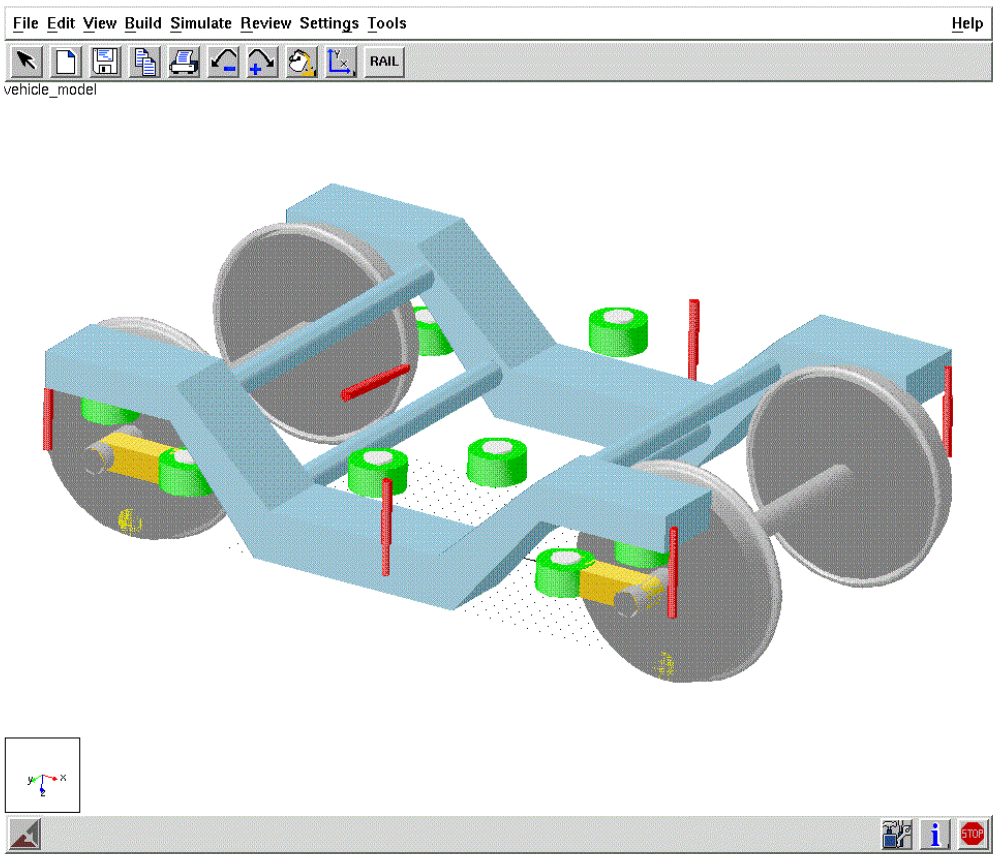


Figure-2 Rendered ADAMS/Rail model of MG Bogie

## 2.3 Detailed description of the rigid bodies, suspension and joints

### 2.3.1 Rigid Bodies

#### 2.3.1.1 Wheel set

Two wheel-sets have been created from ADAMS/Rail system library at the locations provided by the design department. The diameter of the wheel has been kept as 725mm. The mass, moment of inertia and center of gravity assigned to the wheel set and other rigid bodies are shown in the table-1. Two wheel profiles, S1002 (available in the ADAMS/Rail system library) and Indian Railways Worn Wheel profile were used for the purpose of simulation. The worn wheel profile was digitized on CAD and incorporated in Contact model through RSPROF program.

#### 2.3.1.2 Bogie frame

Bogie frame consists of two side frames, which are connected together by two cross tubes. Extrusion tool available in the main toolbox of the software was used to build the side frame. Both the side frames were connected by cross tubes, which were created with the help of cylinder option in the main toolbox.

#### 2.3.1.3 Axle Control arm

Axle Control arm is provided as a rigid link of axle center to the bogie frame having flexible pivots at both ends to simulate the rubber metal bushes. Control arm is created using link option in the main toolbox. Center of gravity is taken at default locations.

#### 2.3.1.4 Car body

Car body is assumed as a lumped mass that rests directly on the bogie via secondary suspension. Car body is created with the help of box option available in the main toolbox of the ADAMS/Rail.

Table-1

| S. no | Name of the Rigid Bodies | Mass (Kg) | Moment of Inertia ($Kg\ m^2$) | | | Center of Gravity (m) | | |
|---|---|---|---|---|---|---|---|---|
| | | | $I_{xx}$ | $I_{yy}$ | $I_{zz}$ | x | y | Z |
| 1 | Wheel set-1 | 885 | 257.4 | 52.2 | 257.4 | -1.075 | 0.0 | -0.3625 |
| 2 | Wheel set-2 | 885 | 257.4 | 52.2 | 257.4 | 1.075 | 0.0 | -0.3625 |
| 3 | Wheel set-3 | 885 | 257.4 | 52.2 | 257.4 | 12.64 | 0.0 | -0.3625 |
| 4 | Wheel set-4 | 885 | 257.4 | 52.2 | 257.4 | 14.79 | 0.0 | -0.3625 |
| 5 | Bogie Frame-1 | 1941 | 775 | 477 | 338 | 0.0 | 0.0 | -0.4862 |
| 6 | Bogie Frame-2 | 1941 | 775 | 477 | 338 | 13.715 | 0.0 | -0.4862 |
| 7 | Control arm-1 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 8 | Control arm-2 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 9 | Control arm-3 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 10 | Control arm-4 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 11 | Control arm-5 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 12 | Control arm-6 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 13 | Control arm-7 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 14 | Control arm-8 | 40 | 0.4431 | 1.7393 | 1.6714 | -- | -- | -- |
| 15 | Car Body | 24200 | 37285 | 967595 | 960538 | 6.8575 | 0.0 | -1.2 |

### 2.3.2 Suspensions

#### 2.3.2.1 Primary Suspension

Primary Suspension is used to satisfy the requirements of axle guidance, stability and steering. Helical coil spring nest, vertical dampers and a resilient bush, as a flexible connection between bogie frame and control arm constitutes the primary suspension arrangement.

An equivalent stiffness of the spring nest is calculated and assigned to the bushing element, which is created from the Rail toolbox menu of ADAMS/Rail software to represent the spring nest. Similarly, a bushing element between the control arm and bogie frame is created assigning the six stiffness values i.e. three translational and three rotational. Vertical primary damper was created using spring/damper option in the main toolbox. For creating damper, stiffness coefficient was fed as zero and the non-zero value of damping coefficient given. Figure-3 shows primary suspension arrangement.

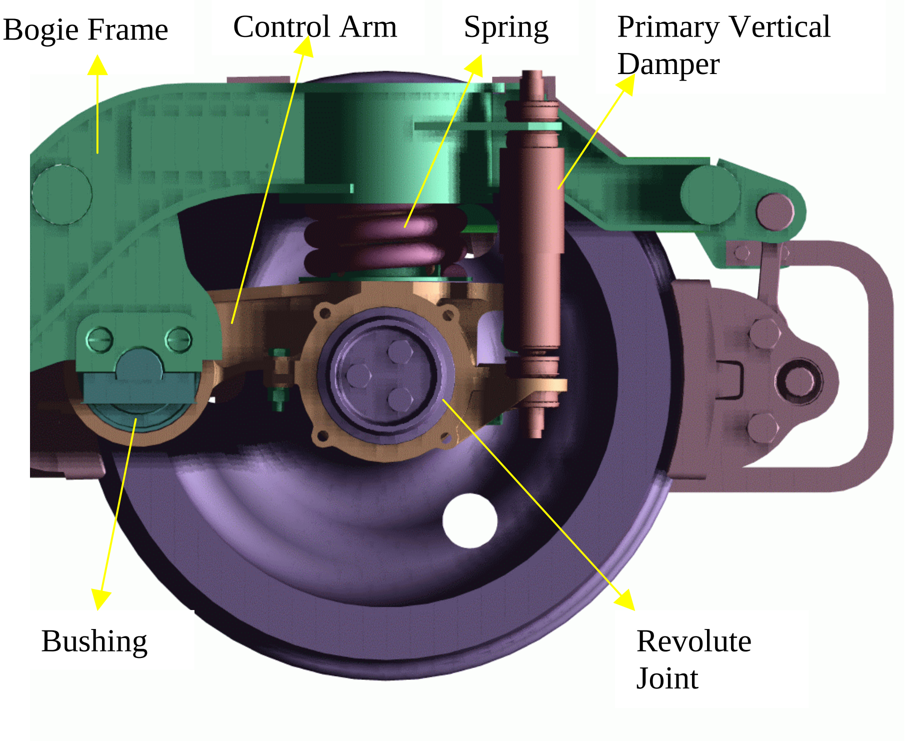


Figure-3 Primary Suspension Arrangement

2.3.2.2 Secondary suspension

Secondary suspension arrangement consists of two parallel nested flexicoil springs with rubber pads placed below & above, a vertical damper and a lateral damper. The secondary suspension arrangement enables lateral and vertical displacements and bogie rotation with respect to car body when running through curves. Ride comfort is significantly influenced by the secondary springs. ADAMS/Rail considerably helped us to optimize secondary spring characteristics. Flexicoil springs were subjected to deflection in all three planes by assigning three-dimensional stiffness. The overall arrangement controls the lateral and vertical motions of the car body relatively to the bogie frame.

As done for primary suspension, bushing element was created from the Rail toolbox to represent the secondary spring nest at the appropriate location with appropriate stiffness values. Similarly vertical damper and lateral damper has been created from the main toolbox assigning appropriate damping coefficient values. Figure-3 shows secondary suspension arrangement.

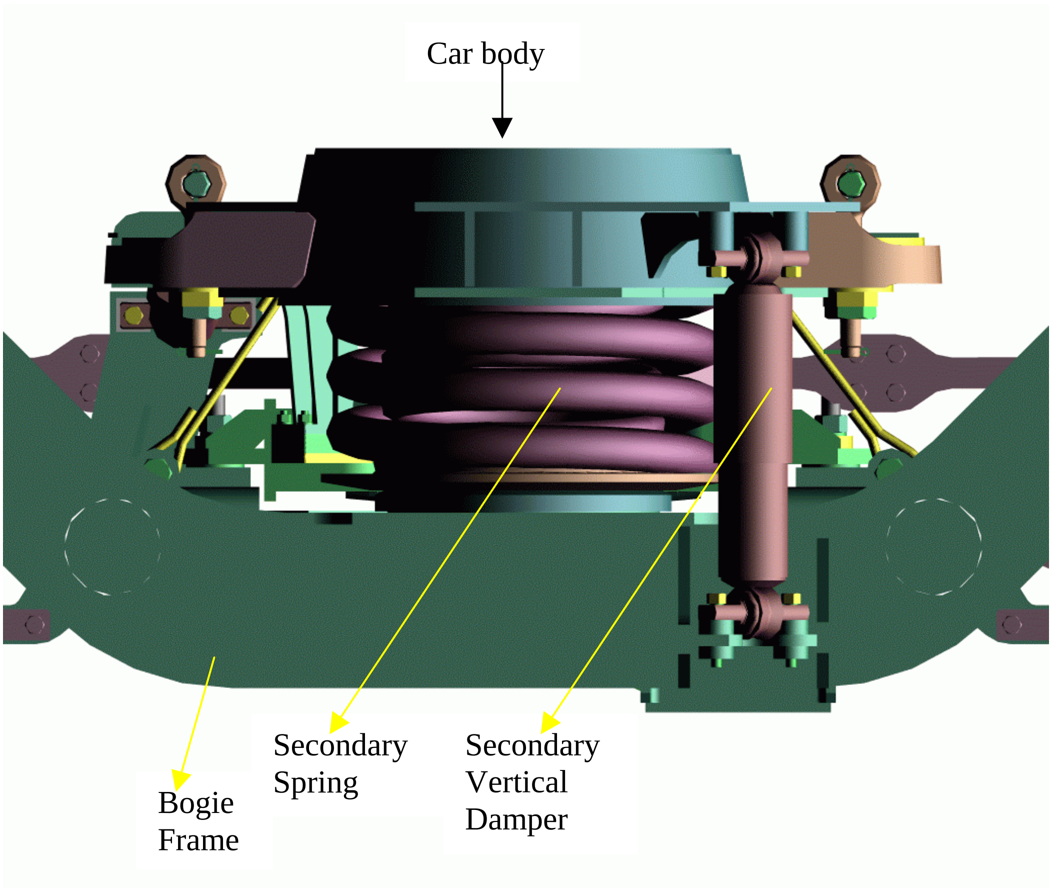


Figure-3 Secondary Suspension Arrangement

2.3.2.3 Center pivot

While the preparation of the vehicle model in ADAMS/Rail all the stiffness values which include traction bar, silent blocks and anti-roll bar were combined to create a single bushing element. Center pivot is used to transmit the traction and braking forces between the car body and the bogie, permitting relatively free lateral and vertical movements. Relatively higher stiffness value is assigned in the longitudinal direction to control impact forces due to traction and braking. Figure-4 shows secondary suspension arrangement.

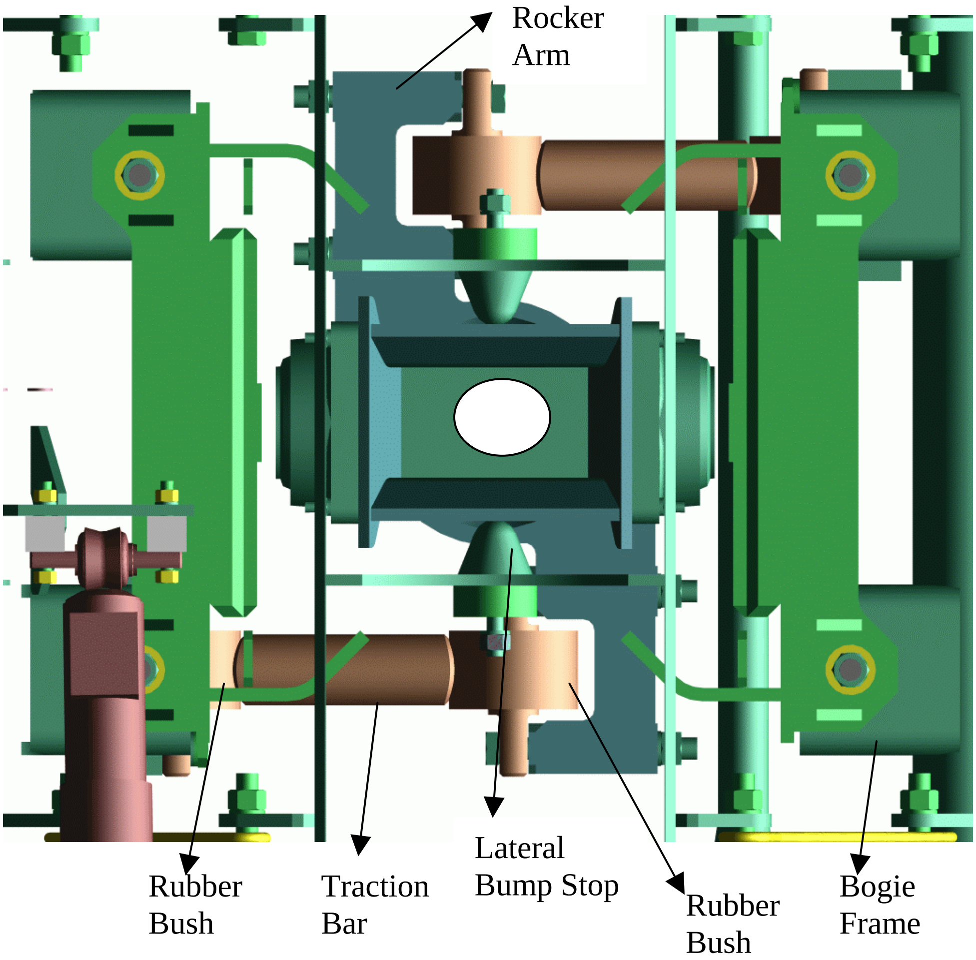


Figure-4 Center Pivot Arrangement

Combined forces that occur from secondary suspension arrangement and center pivot arrangement tend to oppose vertical, lateral, roll and yaw motions of the car body with respect to bogie frame.

### 2.3.3 Kinematic joints (Revolute joints)

Revolute joints from the main toolbox of ADAMS/Rail software were used to connect an axle box respective to the wheel set at each end of the axle. This joint allows the wheel set to rotate around y-axis.

## 3. Contact Model (Level IIa & III)

Level IIa and level-III contact models were created for the analysis. All the input parameters to prepare the wheel-rail interaction model were taken according to the IR's requirement. The maximum lateral displacement of the wheel set was restricted within 6 mm on either side.

To determine maximum critical speed of the vehicle model and comfort index for passenger a wheel rail interaction model level IIa was used. Level III is used to calculate the lateral and vertical forces, derailment quotient and lateral displacement vs conicity plots.

## 4. Simulations

The vehicle was simulated to optimize the suspension arrangements. ADAMS/Rail extensively helped us to achieve the appropriate coefficient values for dampers and springs in all direction to control the within limits the damping of sensitive vibration modes.

The following simulations were carried out during the analysis:

- Pre-loads on primary and secondary springs
- Eigen value analysis
- Stability analysis
- Comfort analysis

The following main results were obtained from the above analysis:

- Lateral and vertical forces acting on wheel sets
- On-loading and Off-loading of wheel
- Lateral forces
- Conicity vs. Lateral displacement
- Limit of track shift forces (Prud'homme criteria)
- Derailment coefficient
- Ride indices

### 4.1 Preliminary Simulations

After preparing the vehicle model, preliminary analysis was carried out to find pre-loads on primary and secondary springs, eigen values and critical speed of the vehicle using level-IIa. A model was simulated with yaw damper and without yaw damper to investigate the hunting critical speed of the vehicle. Sufficient damping was seen without yaw damper, so it was decided to eliminate the yaw damper. Figure-5 shows the ADAMS/Rail generated stability plots using a vehicle model with yaw damper and without yaw damper.

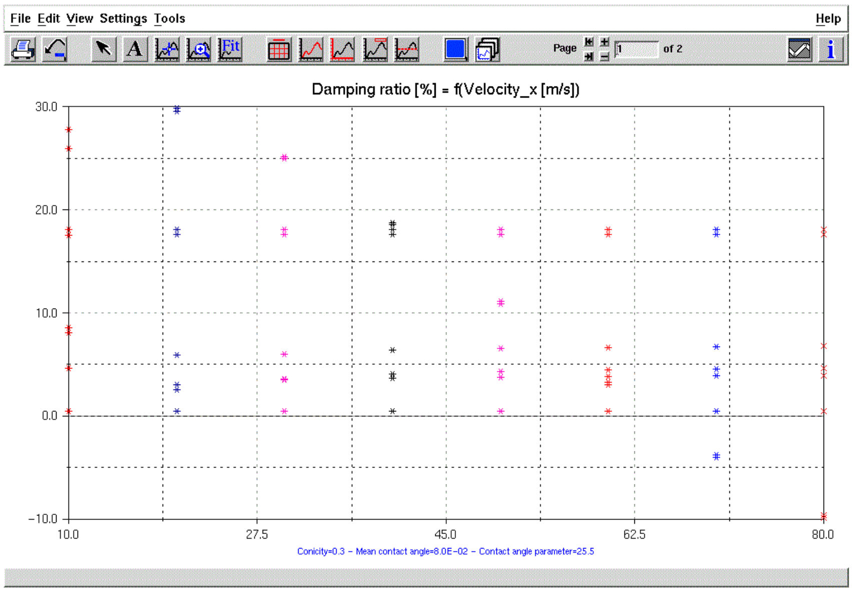


Figure-5 a. Stability plot using a vehicle model without yaw damper

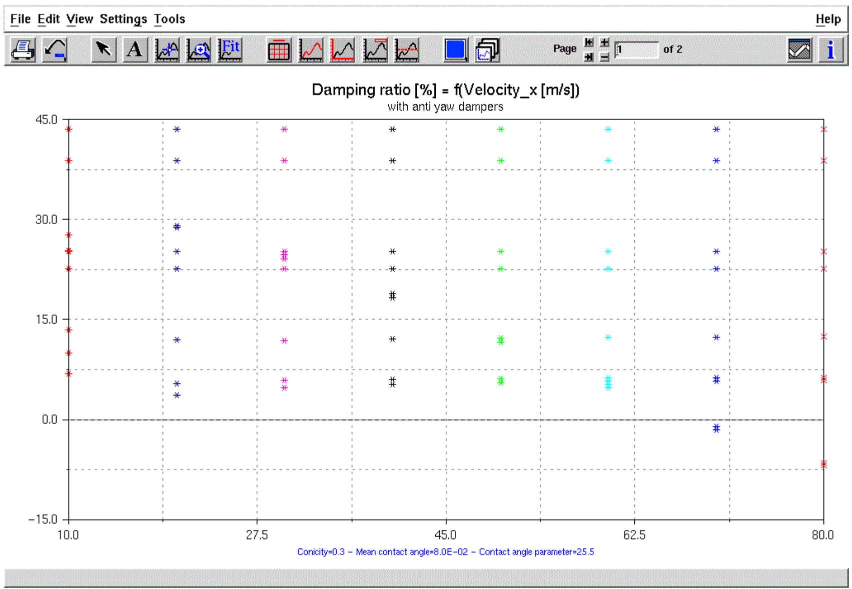


Figure-5 b. Stability plot using a vehicle model with yaw damper

## 4.2 Detailed Simulations

After the results of primary analysis were found to be satisfactory a detailed analysis was carried out with a level-III contact model. A model without yaw damper was used for this simulation. A system model was assembled with a measured IR track to analyze the various results. The detailed descriptions of these results are discussed in Para 5 below.

## 5. Results :

The fundamental requirement of the prototype vehicle is to determine the wheel set unloading to accommodate the disturbance of the tracks with the help of an optimized flexible suspension arrangement. To calculate the percentage off-loading of the leading wheel set of the front bogie, isolated peaks were neglected and the average off-loading of the leading wheel set of the front bogie is calculated which is 25 % as seen in Figure-6.

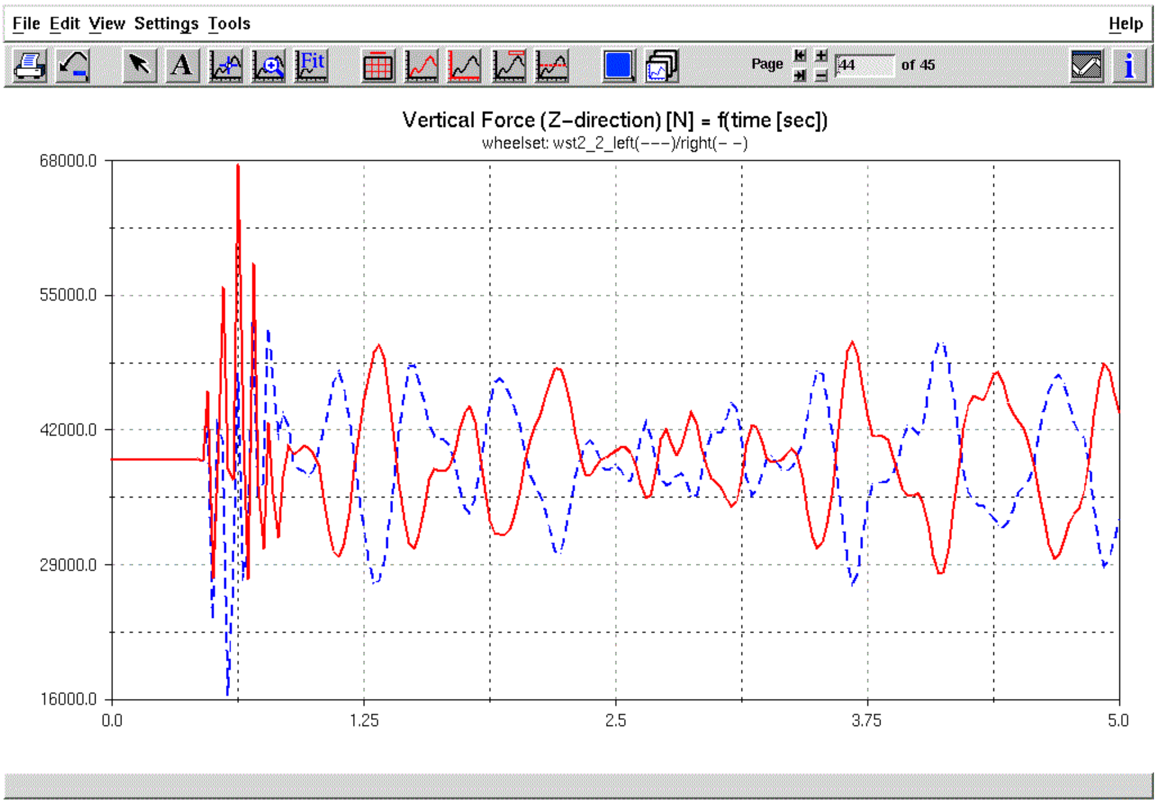


Figure-6 – Results of vertical loading

Lateral forces were checked to investigate that it shall not exceed the lateral strength of the track as excessive lateral forces may cause distortion in the track. As per IR's requirement, a lateral force exerted by the wheel set on the track lasting more than 2 meters should not exceed 1*(10+P/3), where P is an axle load. This requirement is based on Prud'homme criteria. Figure-7 shows that the lateral force is well within limits.

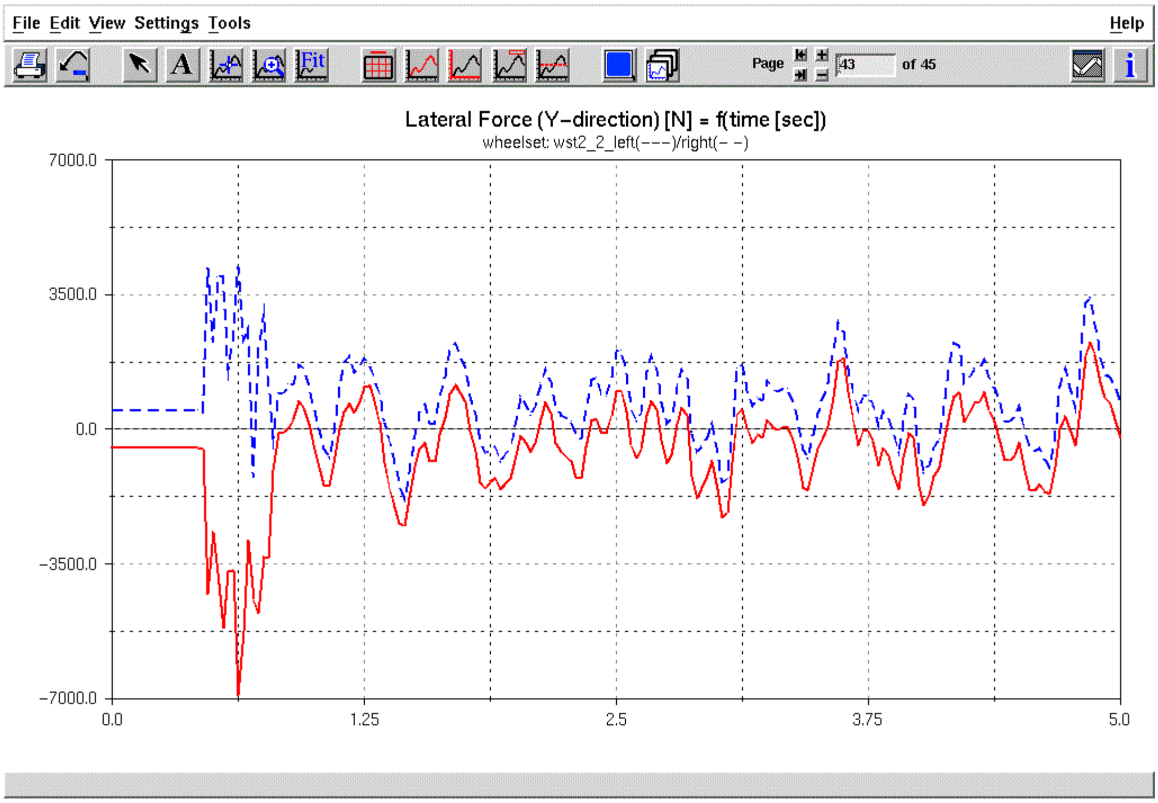


Figure-7 – Lateral load is within Prud'homme value=130.8 KN

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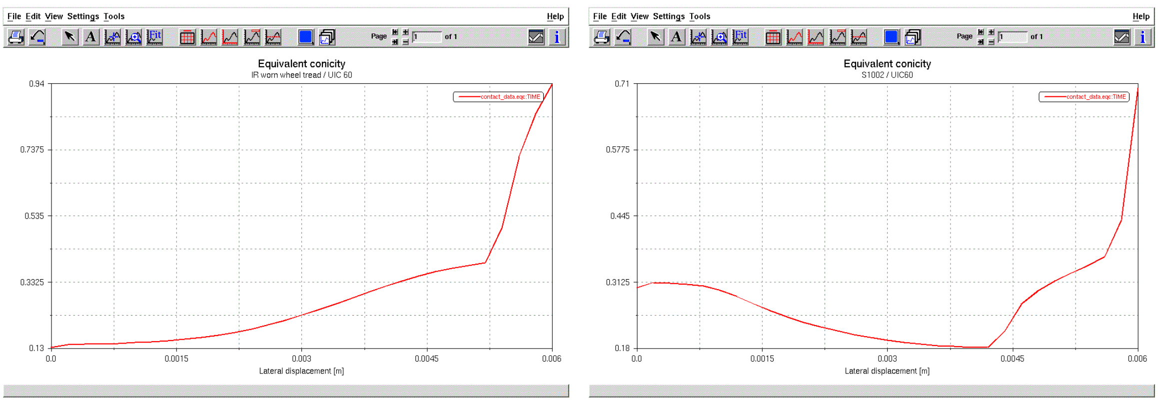
Conicity v/s lateral displacement plot was generated during level IIa contact modeling to identify the range in which the equivalent conicity varies as the wheel set makes 6mm lateral shift with respect to the rail. The plot so generated is shown in Figure-8.




a. IR worn wheel profile with UIC-60

b. S1002 with UIC-60 rail

Figure-8 Equivalent Conicity

Since S1002 profile gives very low conicities at 4 mm lateral distance, existing IR worn wheel profile was chosen.

As per IR's requirement, derailment co-efficient (Y/Q) should be less than or equal to 0.8. Figure-9 given below shows the derailment coefficient (Y/Q) for this bogie, which is found to be within the acceptable range.

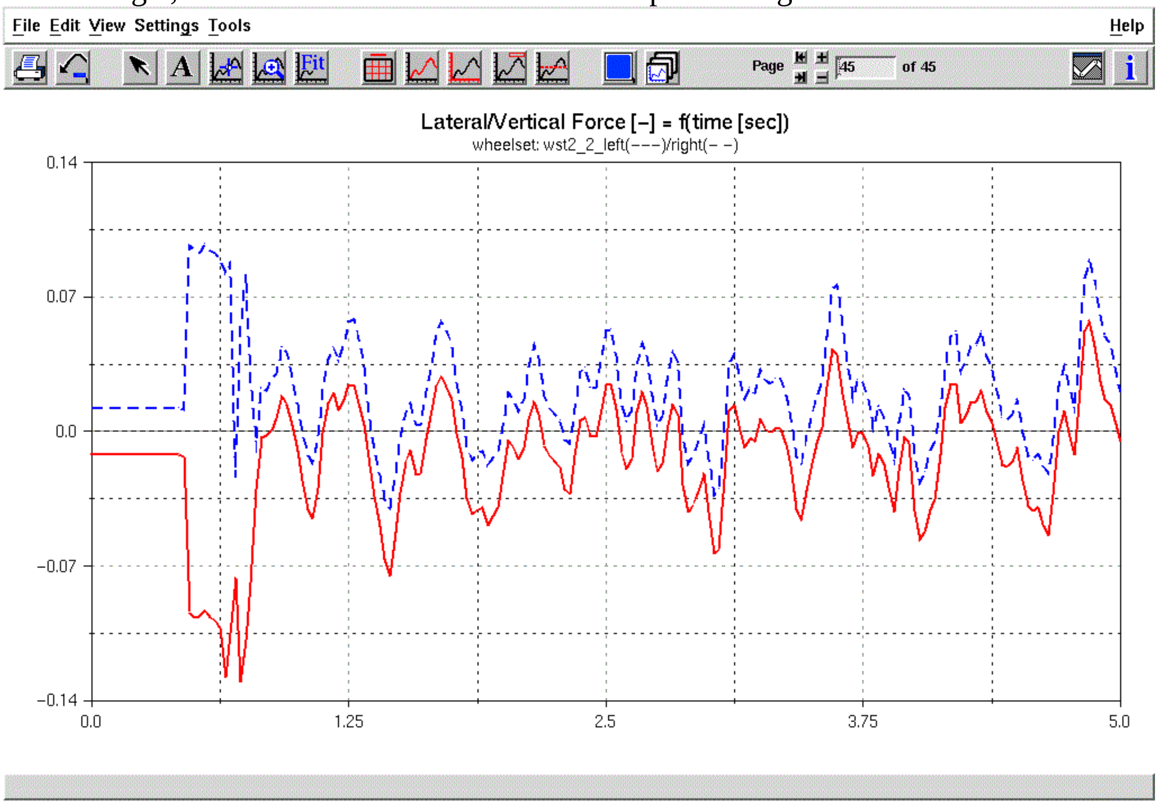
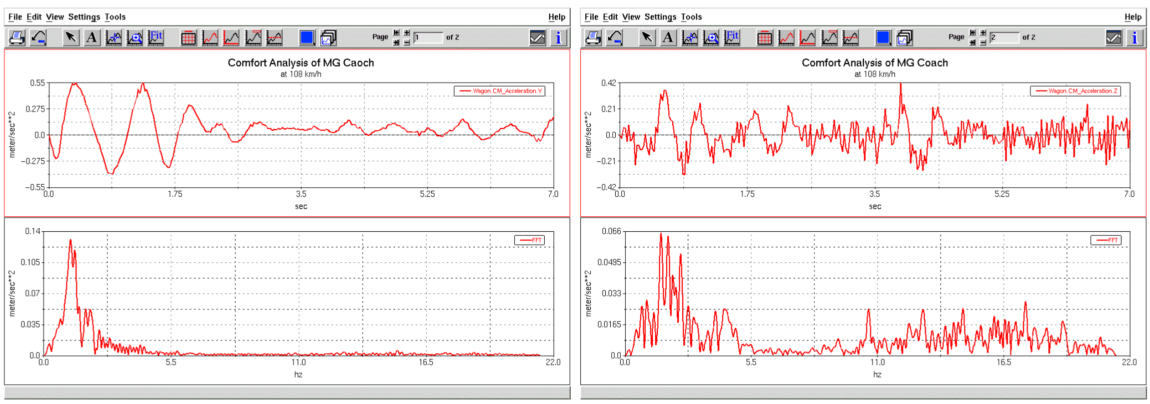



Figure-9 Derailment Coefficient (Y/Q)

Ride comfort analysis has been performed for speeds ranging from 40 kmph to 125 kmph. The analysis has been performed on the system model to calculate the lateral and vertical acceleration of the system. FFT output is taken to get peak accelerating frequency components. Some of the plots are displayed in Figure-10.




a. Lateral acceleration b. Vertical acceleration

Figure-10 Peak acceleration plots using FFT

Comfort Index has been calculated according to the Sperling comfort Index formula. Depending on the track irregularities the ride comfort index at different speeds is shown in table-2.

Table-2

| S.no. | Speed (kmph) | Comfort Index Wz | |
|---|---|---|---|
| | | Vertical | Lateral |
| 1 | 40 | 1.09 | 1.37 |
| 2 | 50 | 1.24 | 1.74 |
| 3 | 60 | 1.31 | 2.15 |
| 4 | 70 | 1.31 | 2.04 |
| 5 | 80 | 1.36 | 1.96 |
| 6 | 90 | 1.37 | 1.83 |
| 7 | 100 | 1.36 | 1.56 |
| 8 | 110 | 1.29 | 1.69 |
| 9 | 120 | 1.29 | 1.71 |
| 10 | 125 | 1.30 | 1.72 |

## 6. Conclusions

ADAMS/Rail has helped Rail Coach Factory, Kapurthala (India) to optimize design of its ‘Y’ frame Meter Gauge bogie.

Based on results of various parameters obtained during simulations, yaw dampers were eliminated and damping coefficients of other vertical and lateral dampers were fine-tuned. Appropriate wheel profile was also adopted. The critical speed of the vehicle has been achieved within the frequency range of 0.1Hz to 10 Hz. The powerful GUI interface of ADAMS/Rail helped in getting a physical feel of the impact of various changes made in suspension elements during the optimization.

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