Modeling of Coaching Container Flat using ADAMS/Rail

Nitin Chowdhary,
Director, Vehicle Dynamics Group,
Ministry of Railways, RDSO, Lucknow, INDIA
&
Ambuj Sharma, Mechanical Dynamics Inc., New Delhi, INDIA

Synopsis

This paper briefly explains the function of RDSO, the usage of Vehicle Dynamics software in the past, the need for ADAMS/Rail software, the initial modeling & analysis done for the Coaching Container Flat as a part of building confidence & validation of the ADAMS/Rail model.

WHY WAS NEED FOR ADAMS/RAIL FELT?

Research Designs and Standards Organization is the research arm of the Ministry of Railways of Government of India. This institution is completely dedicated to research and design work for the entire Indian Railways.

The need to have a central design office for the entire Indian Railways was felt way back in 1903 for ensuring proper coordination amongst various state owned railway systems/small independent units/ railway companies in India. Therefore, for achieving uniformity in all aspects of design of permanent way, rolling stock and other railway equipment, Indian Railway Conference Association (IRCA) was established in 1903. Subsequently, Central Standards Office (CSO) was set up in 1930 to standardize designs and specifications for all classes of materials, plant and rolling stock used all over the Indian Railways. After achieving independence in 1947, CSO was expanded and at the same time separate organization – Railway Testing Research Center (RTRC) was set up in 1952. The primary objective of this organization was to do developmental research and investigation in to railway's problems. In 1957 RDSO was formed by merging RTRC and CSO. Since then, RDSO is continuously engaged in evolving new design and adopting new technologies to efficiently and effectively achieve the goal set for itself by the Indian Railways keeping in view the limited resources and ever increasing demands on railway traffic.

FUNCTIONS OF RDSO:

RDSO is the one single R & D Organization of Indian Railways and functions as technical advisor and consultant to Railway Board – the central decision making body of the Ministry of Railways, various Zonal Railways and Production Units and performs the following important functions**:**

- Adoption, absorption and development of new technologies for use on Indian Railways.
- Development of new and improved designs of rolling stocks and track components.

- Evolving and upgrading standards for material and products needed by Indian Railways.
- Technical investigations, statutory clearances, testing and providing constancy services.
- Inspection of coaches, freight cars, locomotives, signalling and telecommunication equipment and that of track components for ensuring high quality of service.
- Quality audit of railway workshops and coaching depots to ensure high quality of product and services.

With such a vast field of activities and experience, RDSO has given consultancy services to many countries such as Iraq, Sri Lanka, South Korea, Zambia, Egypt, Nigeria and Saudi Arabia in designing, testing and inspecting railway equipment and in doing survey for construction of new lines.

RDSO is headed by Director General. He is assisted by one Additional Director General. RDSO's activities are managed by 5 Senior Executive Directors & 17 Executive Director, who head various directorates, namely: -

Various Directorates of RDSO		
Bridge and Structure	Carriage	Civil
Defense Research	Electrical Loco	EMU & Power Supply
Engine Development	Finance & Accounts	Geo-technical Engineering
Inspection & Liaison	Motive Power	Metallurgical & Chemical
Psycho-technical	Research	Signal
Telecommunication	Testing	Track
Track Machines & Monitoring	Traction Installation	Traffic
Wagon		

RDSO has been accredited with the ISO 9001 certification in July 1999 for 'Developing suitable design for Railway Equipment, Sub-System, Maintenance and Inspection' by M/s DNV Certification BV, The Netherlands.

RDSO has a number of modern laboratories, which are well equipped with research, and testing facilities for development, design evaluation and testing. Some of these are: -

Diesel Engine Development Laboratory	Fatigue Testing Laboratory
Track Laboratory	Geo-technical Engineering Laboratory
Brake dynamometer Laboratory	Metallurgical & Chemical Laboratory
Psycho-analysis Cell	Signal Testing Laboratory
Mobile Testing Facilities	Vehicle Characterization Laboratory

RDSO has played a major role in successful designing and execution of a large number of projects and products. Some of these projects are:-

Establishing various Metro Railways, designing AC Sleeper Coaches, Locomotives, designing high capacity and high speed Wagons, BOXN Wagon, Pre-stressed Concrete Sleepers, Long Welded Rails, advanced bridges and structures, Monitoring of Assets, Reduction of Cost and reduction of damage to environment, designing passenger Rail-Bus, designing Diesel Multiple Units.

Presently, RDSO is engaged in the execution of the following works:-

- Designing of high-speed (180 km/h) passenger coach.
- Upgrading freight operation speed to 100 km/h.
- Development of multi-modal ('Roadrailer') transport wagon system.
- Design and development of 3 phase 6120hp WAP7 type passenger locomotive
- Design and development of 22.5t axle load WAG9H locomotive
- Design and development of Diesel-Electric Locomotives for exports.
- Development of high speed Coaching Container Flat
- Improving Fuel Efficiency
- International research project on rail defect management
- Use of composition brake blocks on rolling stocks.
- Technical collaboration with Institutions of higher education and Industries.

NEED FOR UPGRADATION OF VEHICLE DYNAMICS ANALYSIS CAPABILITIES

RDSO has successful used computer simulation software '**NUCARS™**' for the past ten years for developing new designs of coaches, locomotives and freight cars. This multi-body dynamics analysis software has proved to be invaluable in enabling RDSO designers in their work to evolve and troubleshoot various designs. Ministry of Railways had purchased this software in 1989 from M/s Association of American Railroads, Inc. Pueblo, Colorado, USA (now known as *Transportation Technology Center Inc., USA*).

Over the years, RDSO designers felt the need to accurately model and simulate the complex modern suspension elements and concepts that became popular in the recent past. The needs to correctly simulate scenarios like - a complete train-set, active suspensions, air springs, rubber springs, etc. was very important to the Indian Railways. To ensure good financial health of the organization, reduction in cost of development and testing of a new design was of great importance. It was therefore necessary for RDSO to develop the capability to have a very comprehensive design simulation software so that a 'virtual prototype' could be built and tested on computer without having to incur expenditure in physical testing of railway vehicles. It was therefore decided to upgrade the vehicle dynamics analysis software of RDSO with such software that could build a virtual prototype and subject it to a broad range of 'virtual' tests to analyze the design's performance on the computer itself.

An international tender was floated by RDSO in 1999 for purchasing such a software system. While framing the requirements, extensive survey was done of the various software available in the world. RDSO's objective was to get an accurate and powerful software system and then get the same validated with field test results of a vehicle, which would be tested in field. This was necessary to build enough confidence in the new software since RDSO would be migrating completely to the new system soon after purchasing. Further, RDSO had been using **NUCARS™** for a long time and the designers were very comfortable in using this proven software. A large volume of historical data was also planned to be translated into the new software's format so that work done in the past would not be lost. After the evaluation of technical and financial bids, ADAMS/Rail was purchased by RDSO in 2000.

SIMULATIONS DONE USING ADAMS/RAIL:

After the installation of ADAMS/Rail in RDSO, an exercise was undertaken to model a vehicle in ADAMS/Rail and analyze its simulated behavior. The vehicle chosen for modeling was a Coaching Container flat wagon (hereafter called 'CCF'). RDSO designed this high-speed container flat wagon for transportation of container over the railways. This wagon is planned to be used for quick movement of container cargo over railways to enable a mixed mode operation of goods over both road and rail. The CCF wagon has been designed to run at 105 Km/h on mainline route.

The CCF wagon was designed with a very light underframe weighing only 10.7 tonnes. The payload of this wagon is 41.3 tonnes. The wagon can carry upto three 20 feet long ISO containers. With such a wide variation in the tare to gross weight, it was not possible to use conventional steel helical springs in the bogie suspension. Therefore, it was decided to use air springs in the secondary stage of the CCF.

The CCF can be divided into three main sub-systems:

1) Carbody sub-system
2) Front bogie sub-system
3) Rear bogie sub-system

The carbody is a flat all steel structure weighing 10.7 tonnes. It is designed for carrying standard ISO containers. It is connected to the each bogie through center pivot and two air springs on either side. Load transfer of the carbody is entirely through the air springs. Center pivot gives the necessary rotational freedom to the carbody-bogie system. The air spring system is a self-leveling type of system which maintains a preset height of the under frame in tare as well as gross load. Two lateral and two vertical shock absorbers have been provided on each bogie for providing the necessary damping.

The design details of the coaching container flat are given in *Annexure – I.*

Indian Railways criteria of assessment:

Ride quality and safety assessment of the vehicle was done as per the Indian Railways criteria for such types of vehicles, which is given below:

- Sperling Ride Index (as per British formula) shall not exceed 4.0 in vertical as well as lateral mode.
- The accelerations shall be measured as near the center pivot as possible and its value shall not exceed 0.3g in vertical as well as in lateral mode.
- Isolated peaks of acceleration values upto 0.35g can be permitted provided that the vehicle shows stabilizing trend and does not show any tendency of resonance in the region of peak value.

- The vehicle should indicate generally stable riding characteristics as evident from the movement of bogie on straight and curved track. Wheel on-loading and offloading should be within safe limits.
- Y/Q ratio over $^{1}/_{20}$ second should be less than 1.0
- Lateral wheelset force exerted on the rails for sustained 2 meters distance shall not exceed Prud'Homme's limit of 0.85 $\left(1+\frac{P}{3}\right)$ where P is the static axle load in tones.

MODELING OF CCF ON ADAMS/RAIL

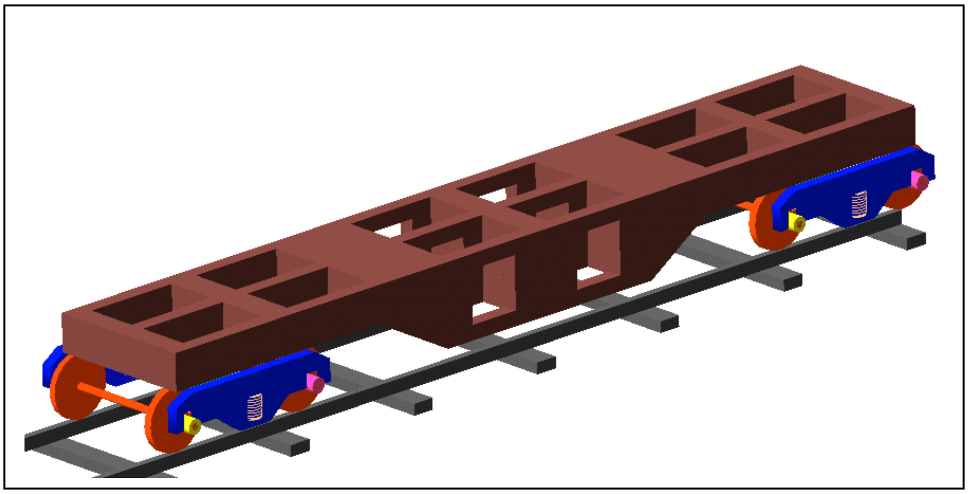
Model of the Coaching Container Flat was created on ADAMS/Rail Ver.11. The basic model consists of the following entities: -

- Car body.
- Front bogie
- Rear bogie
- Standard double wheel set
- Axle box
- Bolster and side bearer
- Primary suspension
- Secondary suspension (air spring)
- Center pivot
- Vertical and lateral dampers.

The carbody is modeled using ADAMS/View as a flat block having mass and Moments of Inertia in three principal directions. The front and rear bogies have also been modeled similarly and have been assigned their respective mass, moments of inertia and coordinates of C.G. Wheelset has been taken from the standard ADAMS/Rail library and modified as per the values of the Indian Railways' wheelset fitted on CCF.
Axle box is also used from the standard library of ADAMS/Rail and the primary spring has been modeled as a linear helical spring having appropriate stiffness and damping values.

Secondary spring (air spring) has been modeled as a Krettek air spring. In the past, RDSO has been modeling air spring using an equivalent mechanical system formulation of the air spring system. This is the first time that we have used a non-linear Krettek element for modeling an air spring.

Center pivot has been modeled as a bushing with relatively very little stiffness in the yawing mode to permit body-bogie yaw. The vertical and lateral dampers fitted on the bogie have been modeled as standard hydraulic dampers.



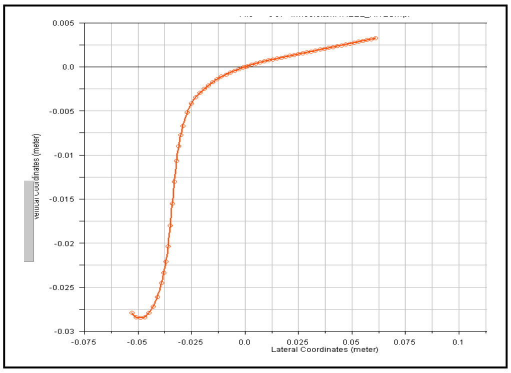
SIMULATION ENVIRONMENT INPUTS

Besides the vehicle model described above, we constructed the wheel rail contact geometry and the track input for simulating the CCF.

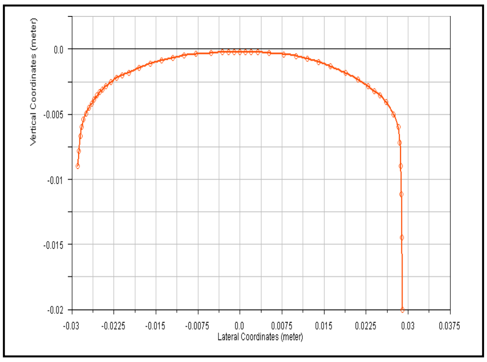
Wheel – rail contact geometry:

Wheel profile of the Indian Railways standard wheel was digitized using CAD software and coordinates of the same were tabulated and fed as a ***.prm** file. Similarly, the rail head profile of the UIC60 rail used on Indian Railways was digitized and its coordinates were fed as the track's ***.prm** file. These two profiles were then superimposed and a general contact configuration was used for simulation of the eight wheel-rail contact points. The Poisson ratio for the material of wheel and rail was taken as 0.27.

The sketch of the wheel profile and the rail profile are given below.



Wheel Profile



Rail Profile : UIC 60

Track input

The track input file was created using measured data taken from the Track Recording Car (TRC), which was physically run on a particular stretch of Indian Railways route. The absolute track parameter values which were recorded by the TRC were imported into EXCEL® program. The various channels captured are- left lateral alignment, left vertical unevenness, right lateral alignment and right vertical unevenness. 600 meters of measured track has been used in the simulation. In order to permit the vehicle to achieve dynamic equilibrium, a perfectly straight track of 1676 mm gauge was created and was added at the beginning to this measured track. The inclination between the two rails is 1:20. The vehicle has been simulated on measured straight track. The process of creation of simulation track is shown in Fig.1 below:

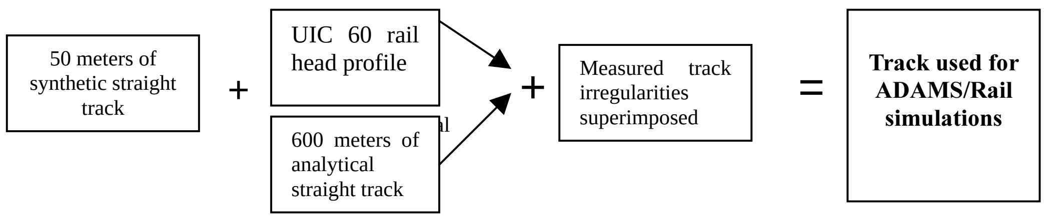


Fig.1

SIMULATIONS ON ADAMS/RAIL

Simulations were done under two conditions:

PRELOAD ANALYSIS

Preload analysis was done to check for the static equilibrium of the vehicle and for checking that the vehicle has been modeled correctly. This was also done to confirm that since the vehicle is a symmetric vehicle, the various loads and deflections observed were equal and that the vehicle is balanced correctly. Preload analysis was done for both empty and loaded condition.

DYNAMIC ANALYSIS

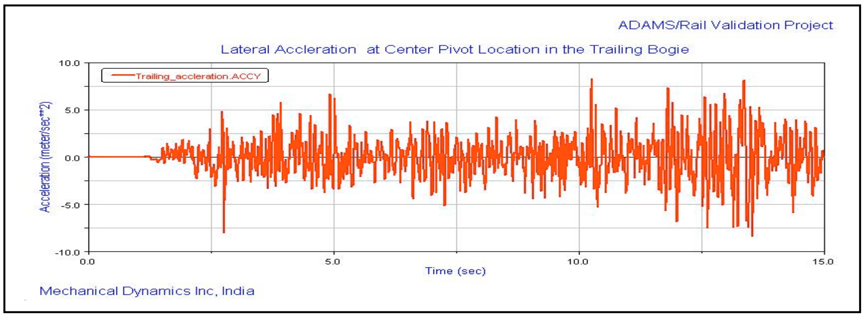
Dynamic analysis of the CCF was done at a speed of 100 km/h i.e. 27.8 m/s for 20 seconds of simulation time i.e. 556 meters of run. Unlike NUCARS, ADAMS/Rail with a very powerful graphical interface helps in visualization and is very helpful in debugging of the model & later in animation of the results. We used the general contact model for the wheel-rail contact configuration.

The output parameters, which were monitored, are: -

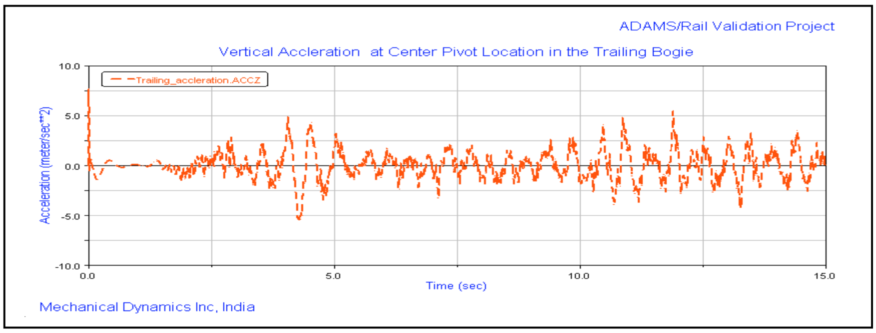
- Vertical accelerations at the front and rear bogie center pivot.

- Lateral accelerations at the front and rear bogie center pivot.
- Vertical and lateral ride index (W_z) as per ISO Sperling method.
- Vertical and lateral ride index (W_z) as per Sperling method.
- Vertical and lateral ride index as per RDSO's Sperling formula.
- S_y and S_z Index as per UIC 518
- ISO Index as per UIC 2631
- Derailment quotient
- Wheel unloading
- Wear number
- Longitudinal and lateral creep forces
- Lateral and vertical forces for all wheels
- Deflections of the primary and secondary suspensions.

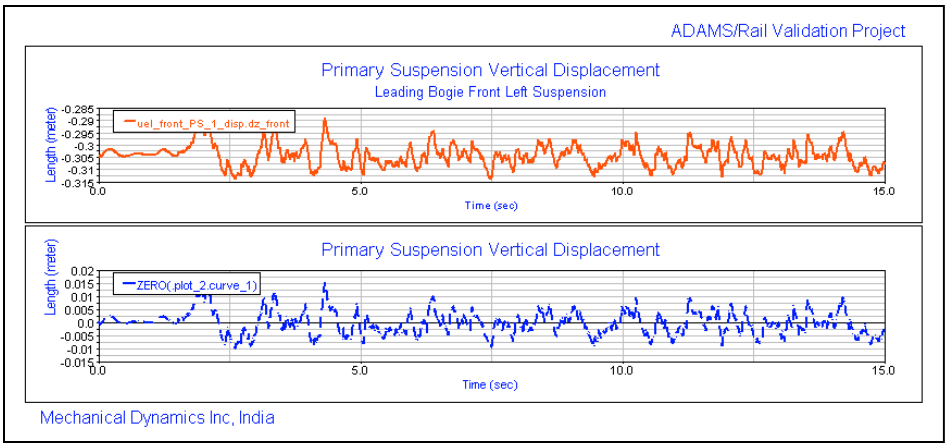
The model was assembled and run successfully. There were no errors in the simulation. The model showed stable running for the entire 20 seconds of simulation. There was no instability in the acceleration plots at the center pivot location. The Y/Q ratio was within the limit of 1.0. A sample plot of vertical displacement of primary spring is given below in Fig 2. The plot does not show any resonance or bottoming out of the spring. Another plot of the vertical acceleration at the center pivot position of the trailing bogie is also shown in Fig 3. The acceleration is generally within acceptable range and does not show any instability.



Lateral Acceleration at the Center Pivot Location



Vertical Acceleration at the Center Pivot Location



Primary Suspension Vertical Displacement

CONCLUSION

The ADAMS/Rail model of the CCF fitted with air springs was thus successfully created and simulated. The model ran successfully and showed that it was a stable design. For the first time, RDSO modeled an air spring as a Krettek element instead of using its mechanical equivalent model.

Annexure

Salient details of the Coaching Container Flat

Parameter details ↓			Empty condition	Loaded Condition
1.	Mass and moment of inertia of Car body	Mass-Mg	10.7	52.00
		Roll-Mg-m^2	5.719	123.00
		Pitch Mg-m^2	408.29	2365.53
		Yaw-Mg-m^2	319.90	2460.16
2.	Mass and moment of inertia of Bolster	Mass-Mg	0.425	0.425
		Roll-Mg-m^2	0.326	0.326
		Pitch –mg-m^2	0.0	0.0
		Yaw-mg-m^2	0.3573	0.3573
3.	Mass and moment of inertia of Bogie frame	Mass-Mg	2475	2.475
		Roll-Mg-m^2	2.789	2.789
		Pitch –Mg-m2	3.267	3.267
		Yaw-Mg-m^2	4.4145	4.4145
4.	Mass moment of inertia wheel axle set	Mass-Mg	1.625	1.625
		Roll-Mg-m^2	1.2906	1.2906
		Pitch –Mg-m^2	0.1185	0.1185
		Yaw-mg-m^2	1.2906	1.2906
5.	C.G. Height of Heavy bodies with free open springs from Rail level	Car Body	1.0135	2.0135
		Bolster	0.7125	0.7125
		Bogie frame	0.7845	0.7845
		Wheel axle set	0.4575	0.4575

* from Rail level

Connection heights of Coaching Container Flat

		Empty	Loaded
1.	Height of side bearer connection from rail level (in m)	0.7052	0.6715
2.	Height of center pivot connection for lateral and longitudinal from rail level (m)	0.6750	0.6413
3.	Height of secondary vertical and lateral connection from rail level (in m).	0.440	0.4063
4.	Height of secondary longitudinal (Anchor link) and yaw connection from rail level (in m).	0.5124	0.4955
5.	Height of primary vertical, lateral, and longitudinal connection from rail level (m).	0.5397	0.5228
6.	Primary spring deflection from free to load in mm.	13.48	47.23
7.	Pre load on one air spring in MN	0.02832	0.1295
8.	Yaw damping due to side bearer MN/m/s	0.00671	0.0326
9.	Primary vertical stiffness of each spring Kg. Mm	76.48	76.48

Body details of Coaching Container Flat

	Parameter		
		Empty	***Loaded***
1.	Tare weight `t'	23	64.3
2.	Pay /Load Gross `t'	-	41.3
3.	Weight of each bogie- `t'	6.15	6.15
4.	Unsprung weight per bogie `t'	3.25	3.25
5.	Wheel base `mm'	28.96	2816
6.	Bogie center distance `mm'	12560	12560
7.	Lateral distance between side bearer(mm)	1600	1600
8.	Lateral distance of primary springs(mm)	2160	2160
9.	Lateral distance of secondary springs(mm)	2250	2250
10.	Capacity of Secondary vertical damp at 10cm/sec.	300	300
11.	Capacity of each sec. Lateral damper at 10 cm/sec.	200	200
12.	Lateral distance of wheel/Rail contact point mm	1742	1742

*****