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Development of a Virtual Prototype Domestic Container Rail Car

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Summary

This paper presents the development of a virtual prototype 45 foot domestic container flat rail car for Ms CONCOR, for operation at a speed of 100 kmph on Indian Railways mainline track. This design has been recently completed and is yet to be manufactured. Adams Rail software version 11.0 and Nucars version 1.z are used to develop and simulate the dynamic behavior of the prototype vehicle. Measured track perturbations of Indian Railways are used for developing a virtual track, with maximum perturbations as allowable in the field. Measured wheel and rail profiles are used to develop the virtual profiles. FEMAP and NASTRAN are used to verify the structural integrity of the virtual prototype. This methodology eliminates the need for manufacturing of physical prototypes at the development stage and for extensive testing, thus reducing the design cycle cost as well as the time to market the product developed.

1. Introduction

Mechanical Design Division of RITES Ltd. was set up in July 1999 and has been providing yeoman service in innovative rolling stock solutions to its clients [1]. One of its clients, Ms CONCOR, placed an order on RITES Ltd. in January 2001 to design a suitable flat rail car for the transportation of 45 foot domestic containers [2], each of 30.5 tonnes capacity, with an additional requirement that the design shall be suitable for transportation of 22' containers of 29.5 tonnes capacity, and 24' domestic containers of 24 tonnes capacity, for carrying traffic of white goods. Furthermore, ISO containers of 20' and 40' with capacity of 30.5 tonnes each would also need to be carried on the same wagon. This was a challenging assignment as it involved the development of a low platform rail flat car, capable of carrying different combinations of loaded containers. Furthermore, the maximum axle load had to be restricted to 20.32 tonnes under all combinations. Also, the location of container locks had to be decided keeping in mind that the containers be placed in a manner that pilferage enroute would be prevented. Furthermore, the dynamic behavior of the vehicle design had to be verified at the virtual prototype stage, including the structural integrity of the under frame.

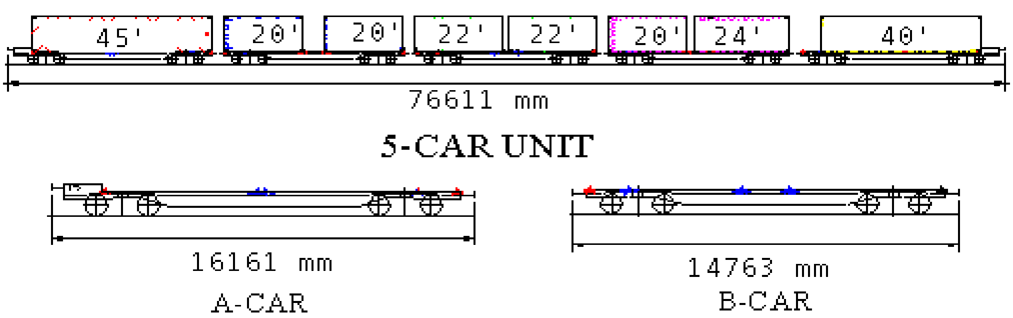

Fig 1:The concept of 5 car consist showing A car and B car separately.

This daunting task was taken up by RITES Ltd. in a methodical manner. Various combinations of bogie centre distances were tried in order to arrive at a working concept to address the above requirements. Thereafter, the concept was frozen and approval obtained from Ms CONCOR as well as the technical advisor of Indian Railways, viz. RDSO, Lucknow. The concept has two types of rail cars, A-car and B-car as shown in fig 1 . A car has a central buffer coupler at one end at a height of 1105 mm and a slackless draw bar at the other end, whereas B car has slackless draw bars at both ends at a height of 845 mm. Two A cars, with three B cars in between, are coupled to form a five car consist. The design has been developed for a commercial speed of 100 kmph operation. A proven bogie [3] and suspension system design as used in existing 40 feet container flats on Indian Railways was used for this wagon, in order to meet the criteria for safety, riding behavior and low track forces, both in the empty and loaded conditions.

2. Development of Virtual Wheel and Rail Profiles

A measured wheel profile as used on Indian Railways was used for simulation. This profile was developed by digitizing it in the format as required by Adams Rail version 11.0. Likewise a measured rail profile of a seven year old 52 kg rail section on Lucknow Kanpur section of Indian Railways was used for the simulation. This profile was developed for use in the simulation in Adams format. The wheel and rail profiles are shown in fig 2 and fig 3 respectively. The gauge used is 1676 mm and the rail cant is 1 in 20 , as used on Indian Railways.

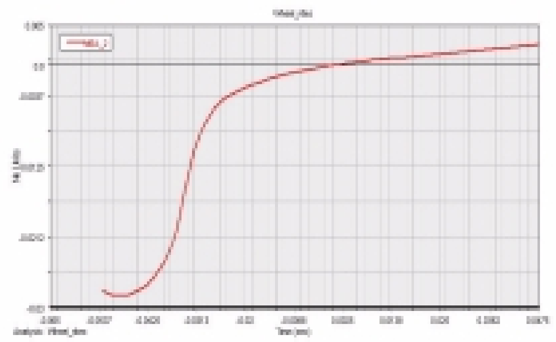

Fig 2: worn wheel profile

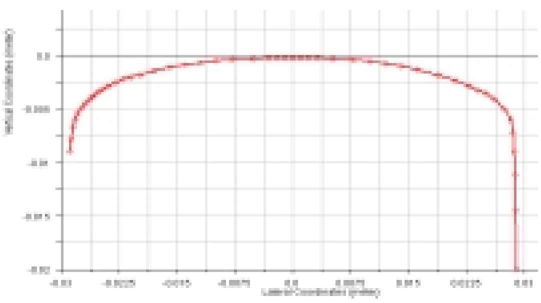

Fig 3: Worn rail profile

3. Development of Virtual Test Track

The virtual track used for simulation was developed from measured track of Jalandhar Pathankot section of Indian Railways. This track data is obtained from Track Recording Car of RDSO. As the data is for a very long section, a portion of 600 metres is captured in Excel worksheet and the maximum lateral perturbations are scaled to 10 mm and the maximum vertical perturbations are scaled to 15 mm for each rail. These are the maximum permissible values for track maintenance for mainline track on Indian Railways as per the Permanent Way Manual. The maximum value of measured track data is larger than the virtual track developed. However the actual track in the field thus has a large number of operating speed restrictions. Simulations were done for 20 seconds at 27.8 metres/sec, viz. for 556 metres length and the simulated track parameters of this 556m stretch are shown in fig 4 and fig 5.

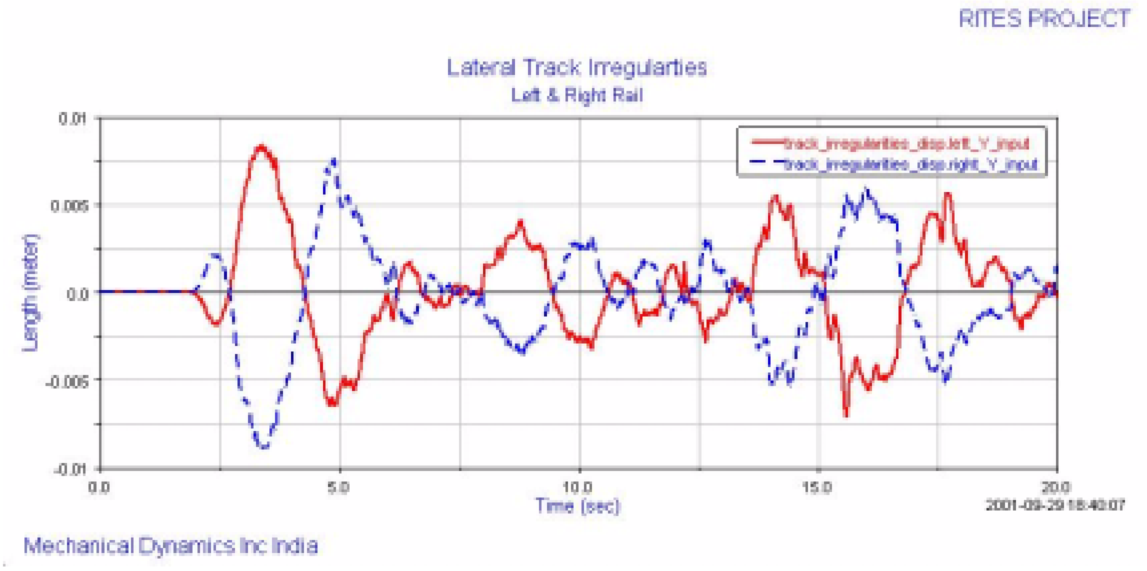

Fig 4: Lateral perturbations of virtual Pathankot track

A straight section of 50 metres without perturbations has been added at the start of the virtual straight track, for static analysis and stabilizing the vehicle. Thereafter the remaining portion of 600 metres has track perturbations. For the simulation on curved track, the same virtual track is used along with a 100 metre transition length after the first 50 metre flat stretch. In the transition portion the super elevation has been progressively increased linearly from zero mm to 80 mm over the length of 100 metres of transition track. Also, the curvature has been similarly increased from zero degrees to two degrees, and the values input in radians in Adams Rail. After the transition curve, the 600 meters track with perturbation has been added, with constant super elevation of 80 mm and constant curvature of 2 degrees.

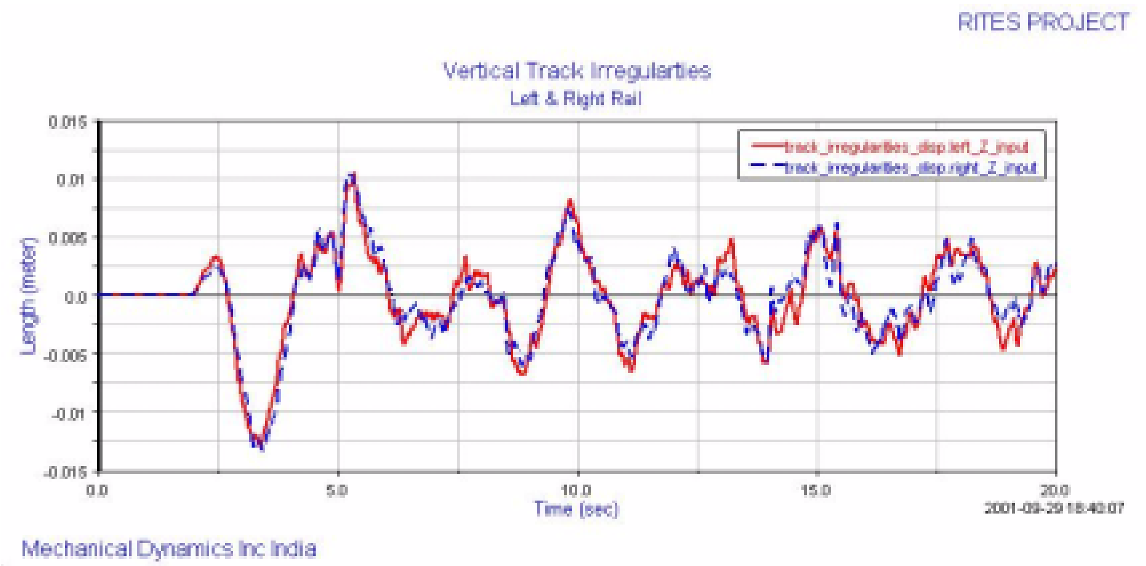

Fig 5: Vertical perturbations of virtual Pathankot track

Both the virtual tracks so developed have flexibility of the rails added to simulate real life field conditions. The values of lateral stiffness [4] of each rail is 1.75E+7 Newtons per metre and lateral damping at each rail is 1.75E+6 Newton per metre. The track vertical stiffness of each rail used is 1.06E+7 N/m and vertical damping value used is 0.54E+5 N/m. The Jalandhar track perturbations for the measured track as well as the virtual track are shown in table 1.

	Jalandhar Pathankot track		
	Measured track perturbations of approx. 10 km length		
S. N.	**Parameter**	**Peak value (mm)**	**Standard Dev. (mm)**
1	Left rail lateral profile	24.00	8.204
2	Left rail vertical profile	29.34	8.646
3	Right rail lateral profile	24.81	8.170
4	Right rail vertical profile	31.04	8.673
	Virtual track perturbations of 556 metres used		
S. N.	**Parameter**	**Peak value (mm)**	**Standard Dev. (mm)**
1	Left rail lateral profile	8.420	2.88
2	Left rail vertical profile	12.75	3.76
3	Right rail lateral profile	8.930	2.95
4	Right rail vertical profile	13.30	3.72

Table 1. Track parameters of field track and virtual track.

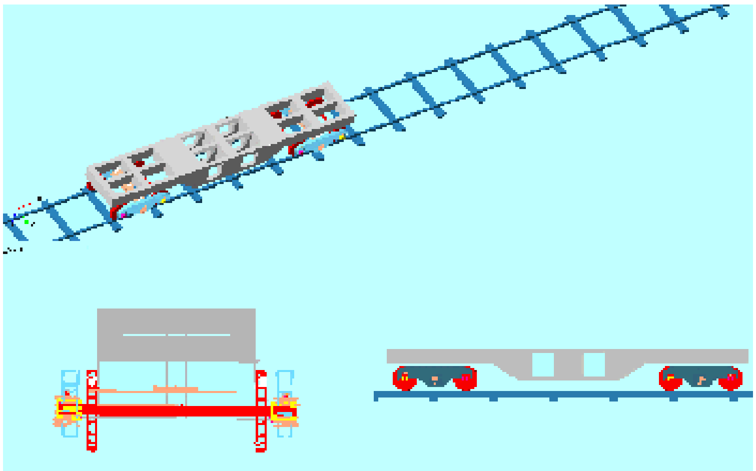

Fig 6: Virtual prototype of B car in Adams Rail

4. Development of Virtual Prototype in ADAMS Rail Version 11.0

Two virtual prototypes of B car were prepared in ADAMS Rail [5] , in empty and loaded conditions respectively. The data that has been used in the models are given at appendix-1. The full vehicle consists of the front and rear bogie sub-assemblies as well as the car body sub-assembly. This is shown in fig 6. The same template is used for both bogies, consisting of two wheel sets, one bolster, two side-frames, and four axle boxes per bogie. Each axle box has a revolute joint. Primary suspension is provided between axle boxes and side frames. The two side frames are connected to each other by a spring plank to keep the bogie square and prevent it from lozenging. The spring plank at side frame locations has a seat for the secondary springs and friction damper springs, between the bolster and the side frames. The car body rests on the centre pivot at the bolster, transferring 10% of the tare weight of the car body. The remaining 90% of the car body weight is transferred at the side bearers to the bolster through side bearer springs. The container pay load of 61 tonnes in the loaded model is taken up at the centre pivots.

5. **Development of a Designer Post processor in Adams Rail Version 11.**

A designer post processor was developed as required by RITES Ltd. and RDSO of Indian Railways. The post processor has been developed for Adams Rail version 11.0 and this post processor has been used for simulation of the virtual prototype developed. It contains the following:

- Sperling Ride Index as per the formula
  RI = Ride Index = $3.56\,(\sum nb^3)^{1/10}(kf^2)^{1/10}(10^6)^{-1/10}(\sum nf)^{-1/10}$, where
  'b' is the value of various amplitude peaks for acceleration (cm/sec^2)
  'n' is the sum of number of peaks corresponding to various 'b' values.
  'f' is the average frequency of acceleration cycles (hertz) and
  The factor kf^2 appearing in the numerator of the radical sign is taken as 1 for freight stock. The acceleration values in this formula are in cm/sec^2.

- Maximum lateral force at the rail, lasting continuously over a distance of 2 metres. For this the concept of moving averages has been used.

- Maximum derailment coefficient, in the form of a ratio between the lateral force and the instantaneous wheel load, lasting continuously over a period of 0.05 seconds. Here too, the concept of moving averages has been used.

6. **Results of Virtual Tests at 100 kmph With Adams Rail Version 11.0**

S N	Description	B car Empty		B car Loaded	
	Virtual track used	Straight	2^0 Curve	Straight	2^0 Curve
1	Ride index vertical	4.862	4.858	4.664	4.660
2	Ride index lateral	2.824	3.291	1.718	2.531
3	Maximum instt. lateral force (N)	13170	14337	105838	81692
4	Derailment coefficient	0.4019	0.6217	0.105	0.4939
5	Maximum vertical accn (m/sec^2)	1.5632	1.6618	0.787	0.253
6	Maximum lateral accn (m/sec^2)	2.385	2.495	0.406	1.723
7	Maximum vertical wheel load (N)	1.46E+5	1.57E+5	2.18E+5	4.62E+5
8	Wheel wear Index on flange (N)	1249	1425	5566	3679
9	RMS vertical accn. (m/sec^2)	0.43	0.462	0.112	0.089
10	RMS lateral accn. (m/sec^2)	0.422	0.701	0.104	0.276
11	Wheel Angle of Attack (degrees)	1.185	1.535	3.242	2.623

Table 2: Results of Adams simulations

The results are post processed for the full length of simulation, including the initial portion of track. However, it is required to develop the post processor further to give the results for specific duration of simulation. Since the vehicle initially takes about two seconds to stabilize, there are peaks in the initial portion thus giving high values of vertical ride index and vertical forces in the results. If this initial portion is not taken into account, then the RI values are close to the field criteria which is a maximum of 4.5 .

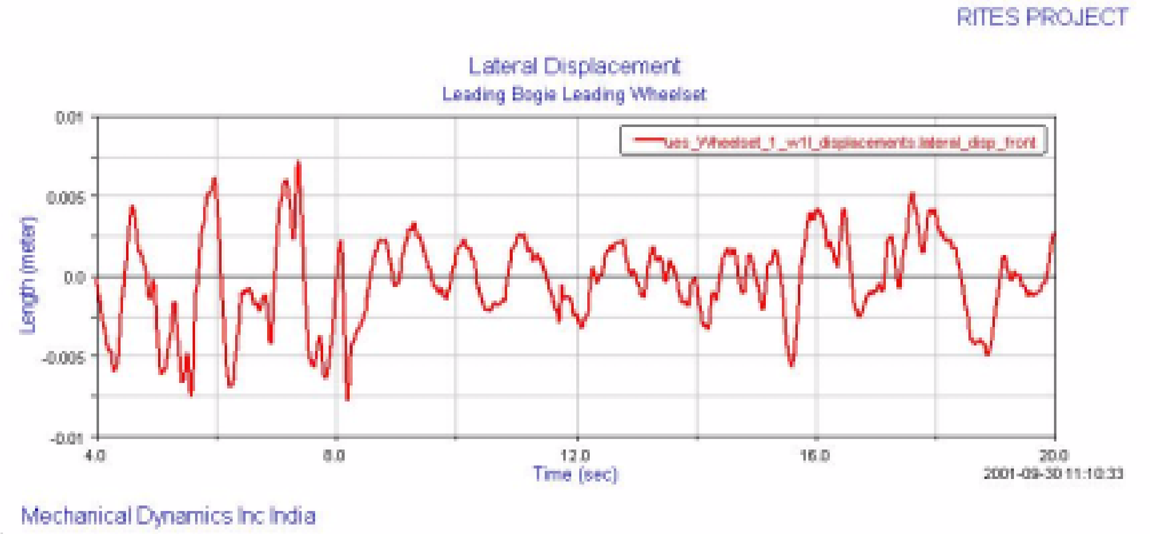

Fig 7: Wheel set 1 lateral displacement of loaded B car on straight track

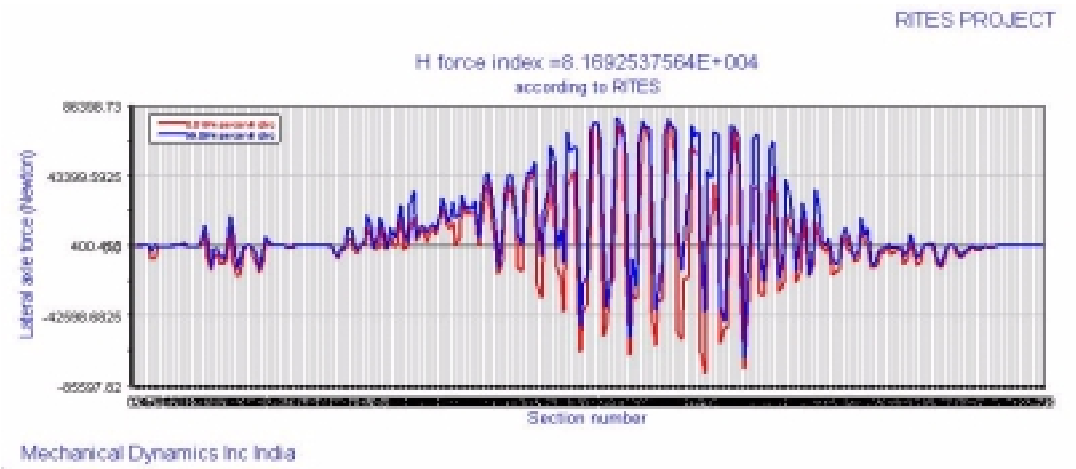

Fig 8: Wheel set 1 lateral forces of loaded B car on 2^0 curved track

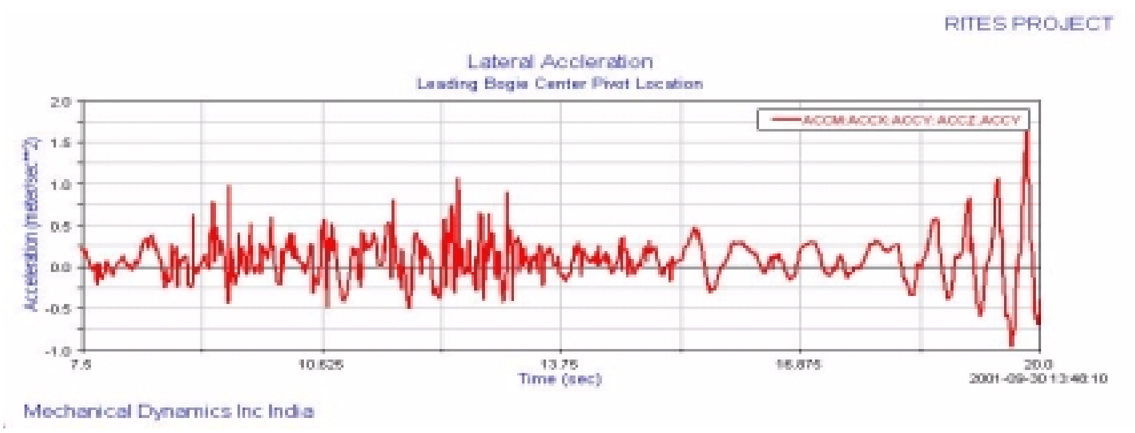

Fig 9: Lateral acceleration at C.P. of loaded B car on 2^0 curved track

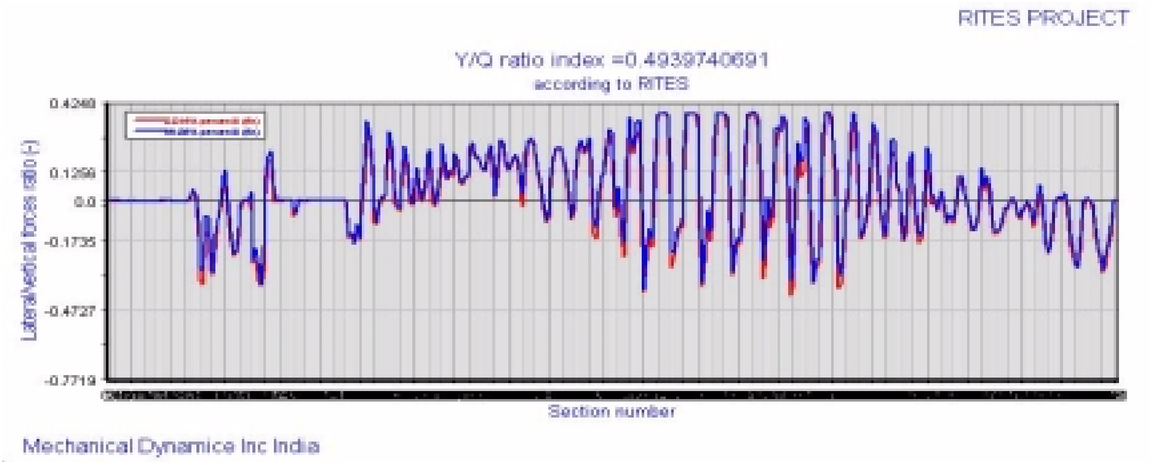

Fig 10: Derailment Co-efficient for loaded B car on 2^0 curved track

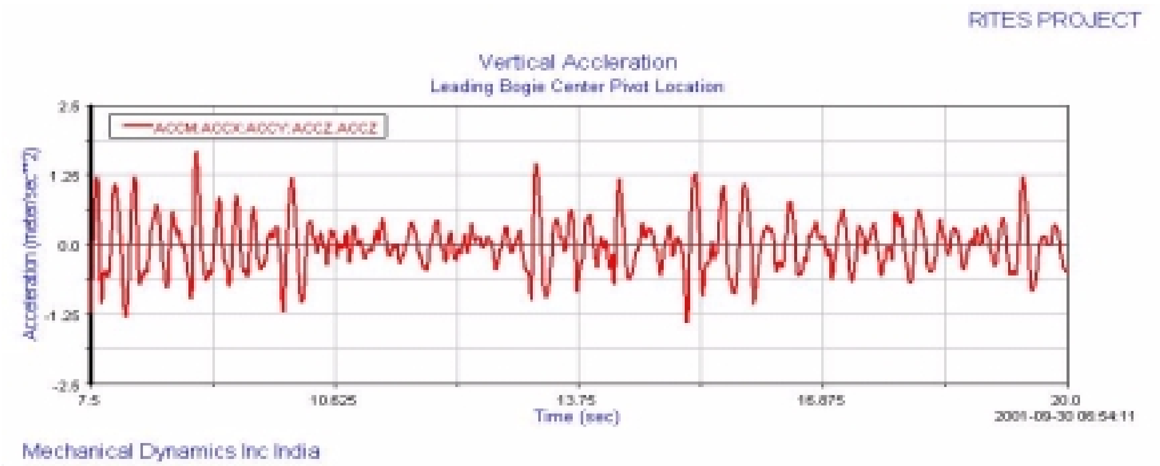

Fig 11: Vertical acceleration at C.P. for empty B car on 2^0 curved track

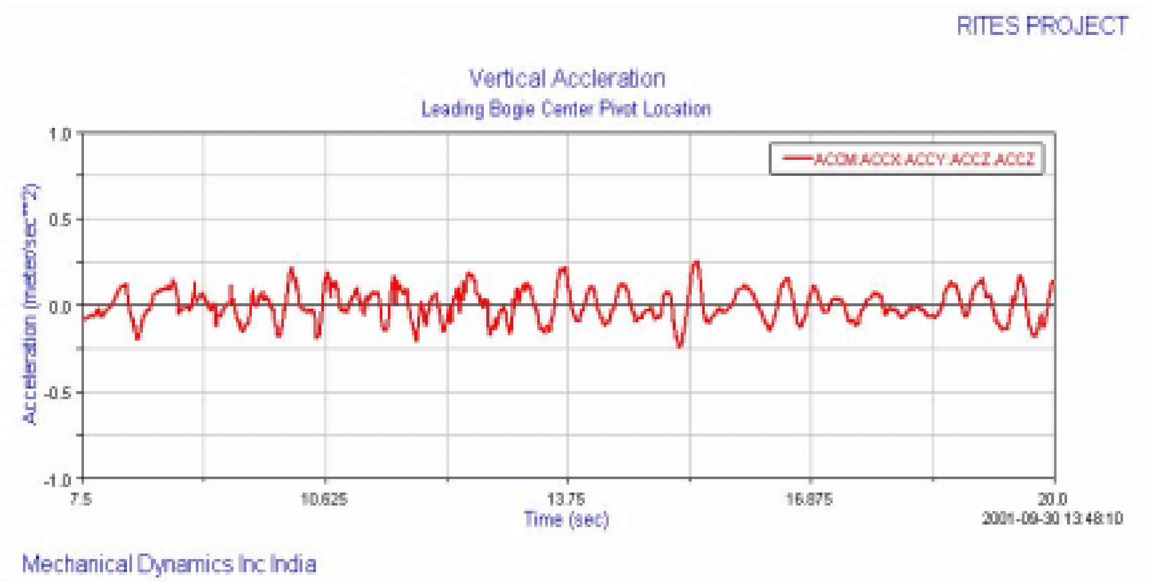

Fig 12: Vertical acceleration at C.P. for loaded B car on 2^0 curved track

7. Development of Virtual Prototype in Nucars

Two virtual prototypes of B car were developed for the vehicle in empty and loaded conditions respectively, and simulations were done using Nucars version 1.z. The same vehicle data was used as used for development of Adams Rail models of B car. However, the primary and secondary suspension in the vertical direction are now modelled as hysteresis loops. In the Adams Rail model, linear values were taken of the vertical stiffness and damping at the condition of tare for both the primary and secondary suspensions, for the empty B car, and at the condition of full load for the loaded B car respectively. The wheel and rail profiles used and rail cant and gauge were the same as taken in the Adams Rail model. The same values of track vertical stiffness and damping were taken as in the Adams Rail model. However, the virtual track [6] was developed from a section of main line track of Katni Bina section of Indian Railways. The virtual track used for Nucars simulation had the following parameters, as in table 3.

	Katni Bina virtual track perturbations of 289 metres length		
S. N.	**Parameter**	**Peak value (mm)**	**Standard Dev. (mm)**
1	Left rail lateral profile	9.980	2.305
2	Left rail vertical profile	11.32	2.568
3	Right rail lateral profile	8.160	2.313
4	Right rail vertical profile	11.41	2.656

Table 3: Virtual track perturbations used in Nucars

8. Results of Nucars Virtual Prototype Test at 100 kmph

S N	**Description**	**B car Empty**		**B car Loaded**	
		Straight	2^0 Curve	Straight	2^0 Curve
1	Ride index vertical	3.347	3.411	3.046	3.188
2	Ride index lateral	3.050	2.931	2.789	2.662
3	Maximum lateral force (tonnes)	1.317	1.237	2.498	3.414
4	Derailment coefficient	0.407	0.5482	0.1793	0.342
5	Maximum vertical accn (g)	0.355	0.411	0.219	0.221
6	Maximum lateral accn (g)	0.212	0.264	0.162	0.171
7	Minimum vertical wheel load (t)	0.98	0.90	7.5	6.6
8	Maximum vertical wheel load (t)	3.8	3.7	12.7	13.6
9	Wheel wear Index on flange	2.65	13.38	3.75	26.94
10	Wheel wear Index total	33.72	72.08	47.99	102.6

Table 4: Virtual results in Nucars

The post processor used in Nucars, SX for straight track and STTC for curved track, was developed with moving averages for calculation of maximum lateral forces lasting continuously over 2 metres, and as well as the maximum derailment co-efficient lasting continuously over 0.05 seconds. The values from Nucars results are well within the criteria developed [7] for virtual testing using Nucars. This criteria is based on vast experience of computer modelling and simulation of Indian Railways vehicles [8], including their field test results. This virtual test criteria envisages that using a specific Katni Bina track for virtual testing, if the envelope of three parameters is adhered to viz. RI = 3.5, Lateral force = 3.75 tonnes and Y/Q = 0.6, then the physical prototype field tests results are achieved within the criteria laid down for field testing of the vehicle during oscillation trials on Indian Railways. Since the Nucars results of 45 foot container B car are within the virtual criteria developed for Nucars, it is safe to predict that the vehicle will pass the field test criteria of Indian Railways when manufactured and tested.

9. Development of Finite Element Model of B Car Underframe

The under frame of the wagon was assessed for structural strength through manual calculations at different sections. Also, a virtual model [9] of the under frame was developed using FEMAP software [10]. Discretization of the model using 4 noded QUAD shell elements and three noded TRIA shell elements was done. The model contained 86,916 nodes and 85,520 elements. All the nodes at one centre pivot location within a diameter of 350 mm were constrained for translation in all 3 axis. All nodes at the other centre pivot location were constrained in the lateral and vertical directions, allowing longitudinal movement due to deflection of the central portion of the wagon due to vertical load as well as due to compressive forces at the draw bar ends. A load of 61 tonnes along with 40% dynamic augment was applied at 48 nodal locations where the containers transfer the load to the underframe of the wagon. Buffing load of 200 tonnes was applied at each end of the centre buffer couplers. This load was transmitted through vertical plates at each end in the draw bar housing in the underframe. Simulation was done using NASTRAN software [11] to simulate the maximum adverse conditions in service and to model the underframe for failure case. The material of the underframe is IS 8500-1991 grade Fe570CuB. This has ultimate tensile strength of 570 Mpa and yield strength of 430 Mpa, for plates having16 mm to 40 mm thickness.

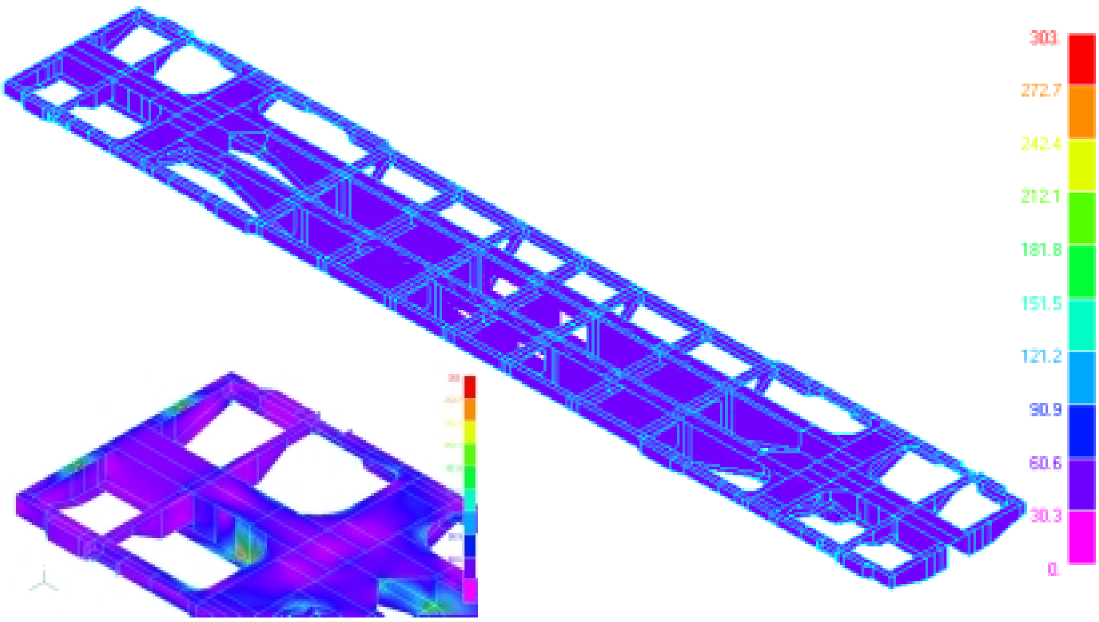

Fig 13: Von Mises stress in fully loaded B car along with buffing forces, with close up in inset.

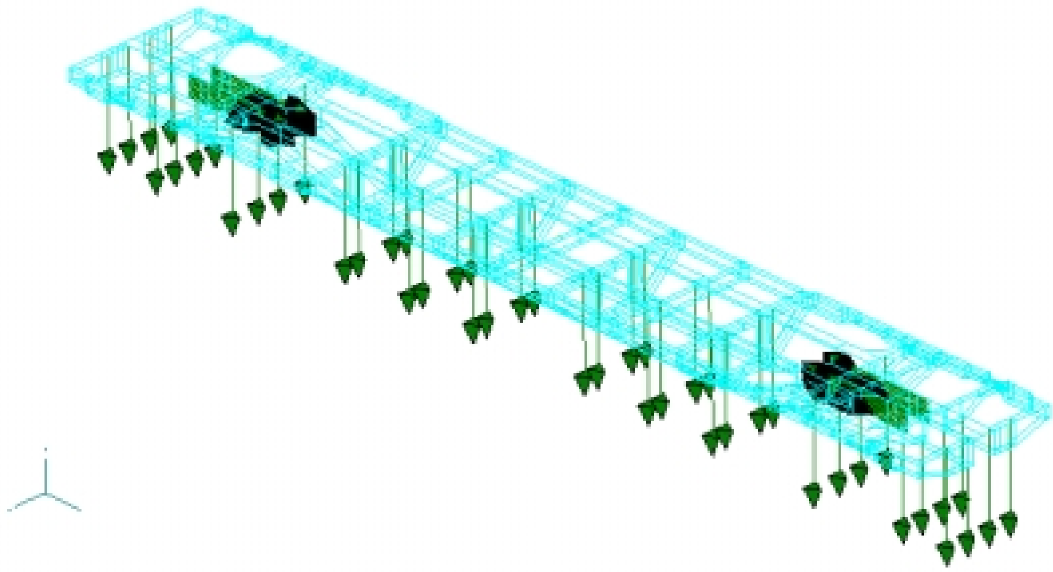

Fig 14: Loads and constraints in Femap model of B car, with buffing forces.

For failure case, the maximum permissible Von Mises stress is taken as 90% of yield stress viz. 385 MPa. During simulation, various design modifications were made to eliminate local stresses by suitable changes to thickness of stressed sections. Also, weight reduction was achieved by reducing thickness of sections with low stresses. After finalizing the model, the stress value found during simulation was 303 Mpa as shown in fig 13. The loads and constraints are shown in fig 14. The maximum deflection was found to be 11.06 mm. For fatigue analysis, the allowable permissible Von Mises stress is two-thirds of maximum stress. The simulations were repeated without the buffing load of 200 tonnes on each end of the wagon, in order to assess the effects of fatigue stresses due to repetitive loading due to dynamic oscillations in service. The maximum stress was found to be 297.9 MPA and the maximum deflection was 6.619 mm. All these values are well within the permitted limits laid down for adequate structural strength and integrity of the structure, and the virtual prototype is found to be strong enough to withstand the forces that are expected in real field life operations of the vehicle when manufactured and tested.

10. Further Development Work

- The underframe of the prototype after manufacture is to be load tested with two loaded containers each of 30.5 tonnes, for evaluating the deflections and stresses and the structural integrity of the underframe.
- Thereafter, oscillation trials on mainline track are to be conducted, to verify the safety and dynamics of the prototype, for a commercial speed of 100 kmph.
- Further development and refining of Adams Rail model is required after the field test results are available.
- The post processor is to be developed further, to output the results of selected portion of simulation, leaving out the initial portion which has poor dynamics as the vehicle needs to stabilize in this part of simulation.
- Virtual test criteria in Adams Rail is to be developed for Indian conditions.

11. Limitations

- The profile of the rail is taken as constant during the simulation, whereas in real life the values may vary significantly along the length of track.
- The profile of the wheel is taken as same for all the wheels during the simulation, whereas in real life the profiles may vary for different wheels of the vehicle.
- The track stiffness and damping parameters are taken as a fixed value throughout the duration of simulation, although soil conditions in the field vary.
- The coefficient of friction at rail-wheel contact has been taken as a constant value of 0.4, but this value would also vary in real life, depending on the condition of rail surface, falling leaves and rain.
- The models assume simplified lumped masses, and the Adams Rail model has been developed with linear suspension characteristics, though in actual it is expected that there shall be a large number of non-linearities in the suspension.
- The location of centre of gravity of each body is calculated and not measured. This would vary, depending on actual manufacture of components and could affect the dynamics of the vehicle.
- A representative value is taken for rubber parameters of stiffness and damping but it is a known fact that characteristics of rubber components vary vastly from piece to piece. After manufacture, vehicle characterization test would help in refining the virtual model.

12. Conclusions

a) Necessary modifications are made at the virtual prototype stage, alleviating the necessity to make modifications to the physical prototype when manufactured. Virtual testing reduces protracted field tests and trials. Viewing animations in Adams software and Nastran gives added confidence to vehicle designers, and helps them in analyzing the structural integrity of virtual prototypes and their dynamics.
b) The detailed design and drawings are completed in a short span of seven months, thus reducing the cost of design and the time to market the flat rail car design developed. The capability of RITES Ltd. for undertaking design and development of rolling stock is established.
c) The results of virtual tests establish that the physical prototype shall pass the field criteria of Indian Railways.

13. References

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[2] CONCOR document No.CON/T/DEV/FLAT-W/2001 dated 15.1.2001 to RITES Ltd. for design of 45 feet container flat wagons.

[3] RDSO report No. MT-94; Oscillation trials on 40 feet BG low platform bogie container wagons on Varanasi-Sultanpur-Lucknow section of Northern Railway, August 1997.

[4] RDSO report No. V-17, Optimisation of elastomeric pad of Standard Casnub BOXN wagons, May 1996, appendix of model file.

[5] ADAMS Rail Technical Manual of Mechanical Dynamics Inc., USA.
[6] RDSO report No. R-41, Development of Track Geometry Input, Aug 1993.
[7] Ravi S. Kochak, Ambuj Sharma, et. al., Development of Container Flat Rail Cars Through Virtual Prototyping; 17th International Association of Vehicle System Dynamics Symposium , Copenhagen, 20th-24th Aug, 2001.
[8] Ravi S. Kochak, Modelling and Computer Simulations of Indian Railway Vehicles; International Workshop on Computer Simulation of Rail Vehicle Dynamics, Manchester Metropolitan University, UK, 23rd-24th June, 1997.
[9] RITES report; Finite Element Modelling and Structural Analysis of Underframe of 45 foot B.G. Container Wagon, July 2001.
[10] FEMAP; Finite Element Modelling and Pre and post processing software, version 7.0, Enterprise Software Products Inc.,USA.
[11] CSA/NASTRAN; Software of Computerised Structural Research and Analysis Corp., USA.

APPENDIX-1

Data Required For Making Virtual Prototype B-Car

Masses and moment of inertia of the car body, bolster, side frames and wheel/axle set about three principal axes passing through respective centre of gravity.

Car Body	Tare	Loaded	Units.
Mass *	9.7	70.7	Metric tonne
I (Roll)	3.761	109.107	Mega Gram. m.sq.
I (Pitch)	176.92	1222.4	- do -
I (Yaw)	184.095	1181.4	- do -

Bolster :		
Mass	0.646	Metric Tonne
I (Roll)	0.4156	Mega Gram. m.sq.
I (Pitch)	0.0	- do -
I (Yaw)	0.3908	- do -

Side Frame :		
Mass	0.807	Metric Tonne
I (Roll)	0.0	Mega Gram. m.sq.
I (Pitch)	0.3404	- do -
I (Yaw)	0.3845	- do -

Wheel Set :		
Mass	1.146	Metric Tonne
I (Roll)	0.7716	Mega Gram. m.sq.
I (Pitch)	0.076	- do -
I (Yaw)	0.7716	- do -

Centre Pivot

Type of Pivot	Flat
Diametre of pivot	360 mm.
Radial clearance	3 mm.

Side Bearer

Lateral distance between side bearer centers on the same bolster = 1750 mm.
Number of springs in each side bearer nest = 2
Pre-compression of side bearer springs under tare = 17.0 mm.

Clearances at side bearers

I. Longitudinal stoppers = 0.25 mm.
II. Vertical stoppers = 10 mm.
III.

Space coordinates and connections

Space coordinates of CGs of all heavy bodies viz. car body, bolster, side frames, wheel/axle set with respect to mid point of lead axle at rail level under tare condition under Body CGs : Location in tare, loaded and fully unloaded (released) condition are indicated as per following format.

Heavy Body	X	Y	Fully un- loaded (released) Z. $	Tare Z $	Loaded Z $
Main Car body	-5.905	0.0	0.586	.5478	1.89435
Leading Bolster	-1.0	0.0	0.585	.5468	0.5027
Trailing Bolster	-10.812	0.0	0.585	.5468	0.5027
Leading frame left	-1.0	1.13	0.470	0.47	0.468
Leading frame right	-1.0	-1.13	0.470	0.47	0.468
Trailing frame left.	-10.812	1.13	0.470	0.47	0.468
Trailing frame right	-10.812	-1.13	0.470	0.47	0.468
Lead bogie lead axle	0.0	0.0	0.420	0.42	0.42
Lead bogie trail axle	-2.0	0.0	0.420	0.42	0.42
Trail bogie lead axle	-9.812	0.0	0.420	0.42	0.42
Trail bogie trail axle	-11.812	0.0	0.420	0.42	0.42

Space coordinate of mid point of all connections between car body and bolster, primary and secondary levels, with respect to mid point of lead axle at rail level under tare condition.

I. Wheel base = 2000 mm.
II. Distance between centre line of bogies = 9810 mm
III. Ht. of centre pivot from rail level = 646.7 mm
IV. Centre pivot dia = 360 mm
V. Ht. of side bearer vertical connection = 773.2 mm
VI. Lateral distance between two secondary spring nest = 2260 mm
VII. Vertical height of each secondary nest from rail level = 392.1mm
VIII. Ht. of elastomeric pad from rail level = 596 mm
IX. Ht. of spring plank from rail level = 252 mm
X. Lateral distance of wheel/rail contact point = 1742 mm
XI. Side bearer vertical stiffness per side bearer connection. = 1.2585MN/m

Connection characteristics

Stiffness and damping characteristics between car body and bolster at the side bearer in vertical, lateral and longitudinal mode, for each nest.

I. Vertical stiffness of spring nest / side bearer 1.2585 MN/m
II. Vertical damping at side bearer 0.0 MN
III. Lateral stiffness of spring nest / side bearer 0.0 MN/m (no restraint)
IV. Lateral damping at side bearer level 0.0 MN --do--
V. Side bearer yaw connection series type stiffness per bogie 5.026 MN.m/RAD
VI. Yaw damping at side bearer per bogie 0.019578 MN.m
VII. Vertical hysteresis loop (if rubber pads are proposed) N/A

Yaw damping at centre pivot (between car body and bolster).

I. Under tare condition 0.0003 MN.m
II. Under loaded condition 0.019174 MN.m

	Secondary Suspension	Tare	Loaded	Unit
Hysteresi s	Secondary vertical stiffness per group	1.7444	3.9087	MN/m
Parll.Pair	Secondary lateral stiffness per group	0.9954	1.997	-do-

Parll.Pair	Secondary longitudinal stiffness/group	35.0	350.0	-do -
Hysteresis	Secondary vertical damping / group	0.00448	0.009394	MN
Parll.Pair	Secondary lateral damping / group	0.00448	0.009394	-do -
Parll.Pair	Secondary longitudinal damping/group	0.035	0.35	-do -

Hysteresis	Vertical stiffness of primary at each axle box	Hysteresis loop given	Hysteresis loop given	MN/m
Parll.Pair	Lateral - do -	4.3245	4.3245	- do -
Parll.Pair	Longitudinal - do -	4.4448	4.4448	- do -
Hysteresis	Vertical damping of primary at each axle box	Hysteresis loop given	Hysteresis loop given	MN
Parll.Pair	Lateral - do -	0.00590	0.00590	- do -
Parll.Pair	Longitudinal - do -	0.00590	0.00590	- do -

Relative pitch and yaw characteristics between the two side frames with spring plank.

I. Relative pitch stiffness 8.77 MNm/Radian/bogie
II. Damping 0.0 MN
III. Relative longitudinal stiffness 53.61 MN/m/bogie
IV. Damping 0.0 MN.

Degrees of freedom of bodies

a) Car body 23456
b) Bolster 2346
c) Side Frame 12356 (1 is longitudinal)
d) Axles 2346 (2 is lateral)

Height From Rail Level when Loaded (mm)

Centre Pivot 602.49
Side Bearer 728.99
Secondary Suspension 368.97
Primary Suspension 595.0
Plank 252.0

Design Particulars

a) Wheel diameter 840 mm.
b) Wheel base 2000 mm
c) Bogie center distance 9810 mm
d) Tare weight of wagon 18.804t
e) Static deflection car body CG
Under tare 37.2 mm
Under load 82.23 mm
f) Height of car body CG from rail level under tare 547.8 mm

g) Height of CG of the car body of the fully loaded vehicle from rail level under fully released condition of primary and secondary vertical springs 1976.6 mm

Clearances

a) Gib clearance at axle box between side frame and axle boxes.
I. Lateral 13.25 mm
II. Longitudinal 6.25 mm
b) Lateral Gib clearance between bolster and side frame at secondary stage 12.5 mm
c) Lateral clearance between body and bolster at center pivot 3 mm

Spring Particulars

Spring details of all the springs used at various levels viz. primary, secondary springs (inner, outer, snubber) side bearer springs etc. with following particulars:

Inner Outer Snubber Side Bearer

a)	Free height (mm)	243	260	288	123
b)	Home height (mm)	180	176	175	84
c)	Mean coil diameter(mm)	72	118	86	101
d)	Number of turns (effective)	8.75	7	9	3
e)	Wire diameter (mm)	18.5	22	17.5	21
f)	Stiffness (kg/mm)	36.561	20.763	16.701	64.143
g)	No. Of Springs/nest	6	7	2	2

Co-efficient of friction

a)	Side bearer	0.52
b)	Centre pivot.	0.52

Piece wise linear characteristics for Secondary and Primary vertical connections
(given as hysteresis loops in Nucars as applicable to B Car of Container Flat Wagon. Units are Mega Newton for top row, and metres for bottom row.)

1. Secondary vertical Spring-wedge block connection for Empty vehicle (5 break points).

Extension PWL	5	- 35.2708	- 0.2708	- 0.03371	- 0.00590	0.0
		- 1.108	- 0.1076	- 0.045	- 0.0280	0.0
Compression PWL	5	- 35.2960	- 0.2960	- 0.04425	- 0.01245	0.0
		- 1.108	- 0.1076	- 0.045	- 0.0280	0.0

2. Secondary vertical Spring-wedge block connection for Loaded vehicle (5 break points).

Extension PWL	5	- 350.2708	- 0.2708	- 0.03371	- 0.00590	0.0
		- 1.108	- 0.1076	- 0.045	- 0.0280	0.0
Compression PWL	5	- 350.2960	- 0.2960	- 0.04425	- 0.01245	0.0
		- 1.108	- 0.1076	- 0.045	- 0.0280	0.0

3. Primary vertical Elastomeric pad connection PWLS as applicable both to empty and loaded B Car (7 break points).

Extension PWL	7	-0.17642	-0.12365	-0.0674	-0.04681	-0.02467	-0.00237	0.0
		-0.00514	-0.0044	-0.0033	-0.00272	-0.00199	-0.00133	0.0
Compression PWL	7	-0.19838	-0.15275	-0.1074	-0.08887	-0.05573	-0.02903	0.0
		-0.00514	-0.0044	-0.0033	-0.00272	-0.00199	-0.00133	0.0

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