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AN APPLICATION OF THE ADAMS/RAIL MODULE TO MODELLING AND EXAMINATION THE BIMODAL TRAIN

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1. INTRODUCTION

The bimodal transport is a subsystem of the combined transportation system. Combined transport integrates shipment of goods on road and rail without transhipment when changing from road to rail mode and vice versa. In Western Europe a combined road/rail transport has been in operation for several years now.

A special position in this system belongs to the bimodal transport, which meets the requirements of road and rail transport and completely eliminates vertical movements of units load during mode changing - Fig.1.

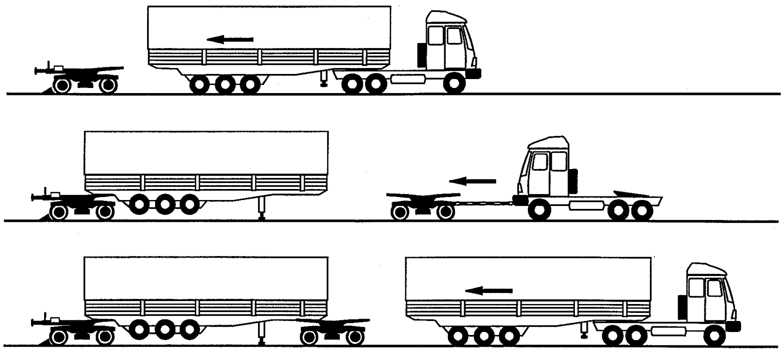

Fig.1 The principle of compose bimodal train,
courtesy by „Research Institute of Rolling-Stock Industry", Poznan

In Poland the development of the bimodal train started several years ago and in 1994 for the first time a prototype of the train was displayed in Poznan during The International Mess.

The photograph of the Polish three-unit prototype train is shown in Fig.2.

Fig.2 The photograph of the Polish three-unit prototype train

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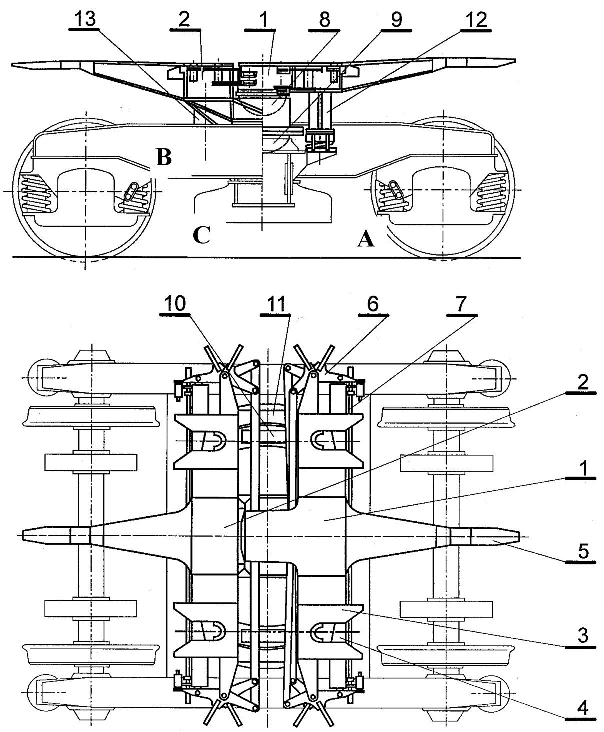
The loading units such as containers, cisterns and trailers form the train after clutching through adapters to bogies. At the front and the end of the train the loading units connect with one front/rear bogie and one intermediate (Jacob’s) bogie. All the other units are connected through adapters to the intermediate bogies. Each intermediate bogie carries 2 semi-adapters, which allow relative yaw, roll and pitch of the adjacent units.

2. DESIGN OF THE PROTOTYPE TRAIN

The train consists of three bimodal units. In the train structure there are 4 railway freight bogies and three bimodal car bodies in the form of one semi-trailer and two cisterns as shown in Fig.2. Each car body is equipped with its own carrier structure. In this way the railway frames are eliminated. The train needs only bogies, car bodies and adapters. The adapters are the light frames equipped with special locks necessary to connect body with the bogie. The design of the bimodal bogie is based on the standard Y25 freight railway bogie. There are some details, which differ the bimodal bogie from the standard design. Each of bimodal bogies possess swing bolster, which can move laterally to the longitudinal axis of the bogie. The Fig.3 shows semi-adapters of the intermediate (Jacob's) bogie. This bogie connects two adjacent car bodies.

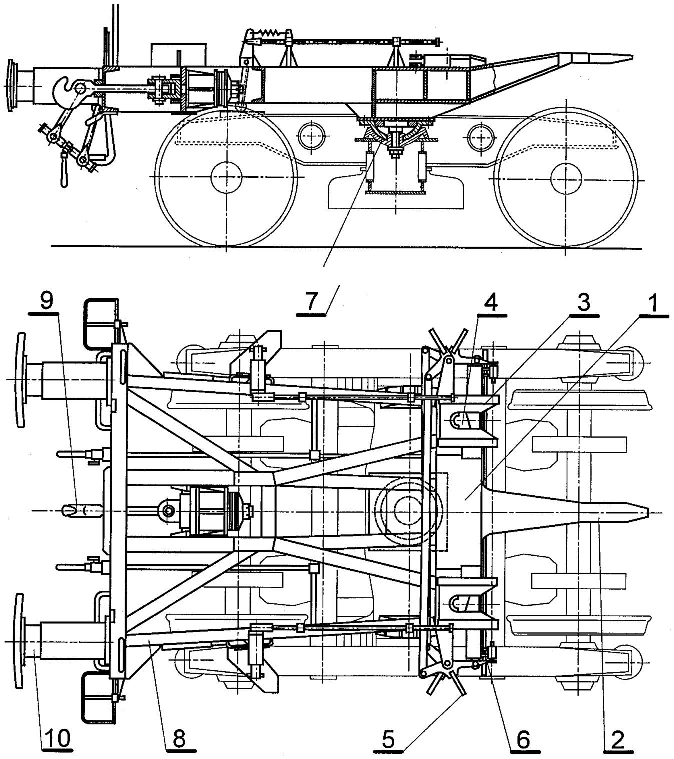


- A - wheelset
- B - bogie frame
- C - swing bolster with hangers

- 1,2 - upper/lower adapter
- 3 - side support for the car-body
- 4 - lock of the adapter
- 5 - reaction arm
- 6,7 - the lock mechanism
- 8,9 - upper/lower bogie pivots
- 10,11 - side friction block of the upper/lower adapters
- 12,13 - adapter’s supports

Fig.3 Intermediate (Jacob's) bogie
courtesy by „Research Institute of Rolling-Stock Industry", Poznan

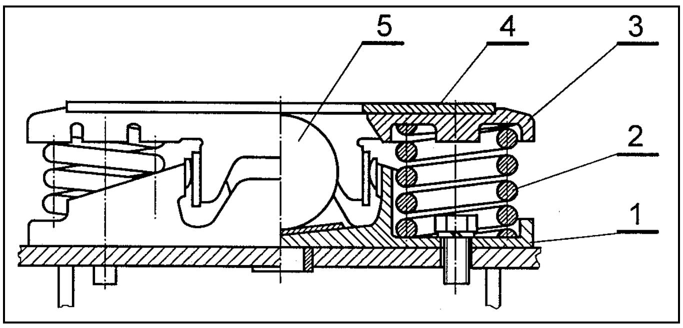
The side supports „3” and adapter’s locks „4” are used to mount the end of the car body on the bogie frame „B”, utilising the swing bolster „C”. The reaction arm „5” engages with the car body nest, which is placed at the bottom end part of the car body. Vertical load from the car body is transmitted to the adapter by the side supports and reaction arm, and then to the bogie frame via spherical bogie pivots. Side friction blocks „10” and „11” receive the load caused by roll of the car body, when the train moves.



1 - adapter
2 - reaction arm
3 - side support for the car body
4 - nest of the support
5,6 - the lock mechanism
7 - bogie pivot
8 - adapter’s frame
9 - coupling screw
10 - stop end (spring buffer)

Fig.4 Front (leading) and rear (trailing) bogie of the train
courtesy by „Research Institute of Rolling-Stock Industry", Poznan

Leading/trailing bogie has a single adapter „8” with coupling screw „9” and the bumpers „10” - Fig.4. The other equipment of this bogie is the same as for the intermediate bogie.



1 - housing
2 - coil spring
3 - upper plate
4 - friction plate
5 - roller

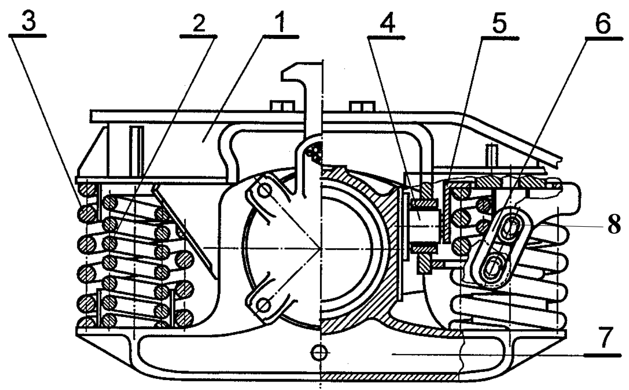
Fig.5 The Side Friction Block,
courtesy by „Research Institute of Rolling-Stock Industry", Poznan

The side friction block differs from that applied in Y25 bogie. A steel roller „5” limits the deflection of springs „2” in the housing „1”, see Fig.5. The friction plate „4” contacts with its counterpart on the adapter.

2.1 The primary suspension

The primary suspension of the bimodal bogie consists of two nested coil springs and friction damper shown in Fig.6. The inner spring „2" is loaded only when the vehicle is laden. The primary friction damping is provided with hornguides and is changeable with the load via the inclined Lenoir link „6". The damping in the bogie suspension comes from friction in friction dampers. The response to excitation of a vehicle with such a suspension is extremely non-linear.

The friction force acting on the primary friction face is a function of the outer coil spring load. The damping acts laterally and vertically. The pre-loading force, applied by the Lenoir link, makes the primary suspension very stiff longitudinally.



1 - bogie frame
2,3 - spiral springs
4 - sliding block
5 - holder
6 - Lenoir link
7 - housing of the axle-bearing

Fig.6 The Primary Suspension,
courtesy by „Research Institute of Rolling-Stock Industry", Poznan

2.2 The secondary suspension

The secondary suspension is provided by a swing bolster, connected to the bogie frame by two pairs of hangers. Each bogie has the pivot's nest, placed at the centre of the swing bolster. The spherical pivot and adapter create the unit, which transmits vertical load from the car body to the bogie frame, and then to the wheelsets.

3. THE MODEL OF THE TRAIN

3.1 Kinematic structure of the model

We used the licensed ADAMS/Rail 9.1 simulation package to build our model of the bimodal train. The elements of the model are indicated in Fig.7.

The model was built in two steps. In the first step we designed a single, two-axle bogie model, and in the second step a complete train model. We started with creating the wheelset and the elements of the bogie frame, which are shown in Fig.8.

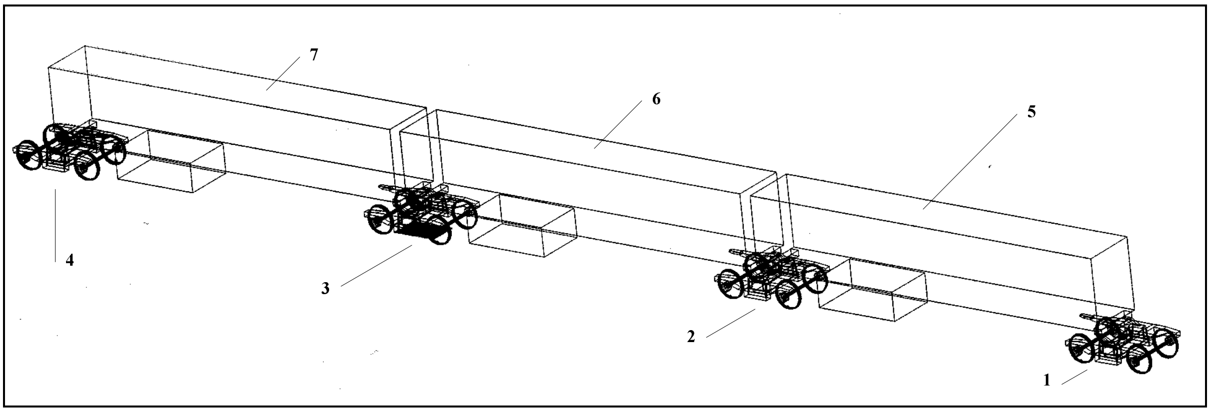


Fig.7 The structure of the bimodal train model - Adams/View

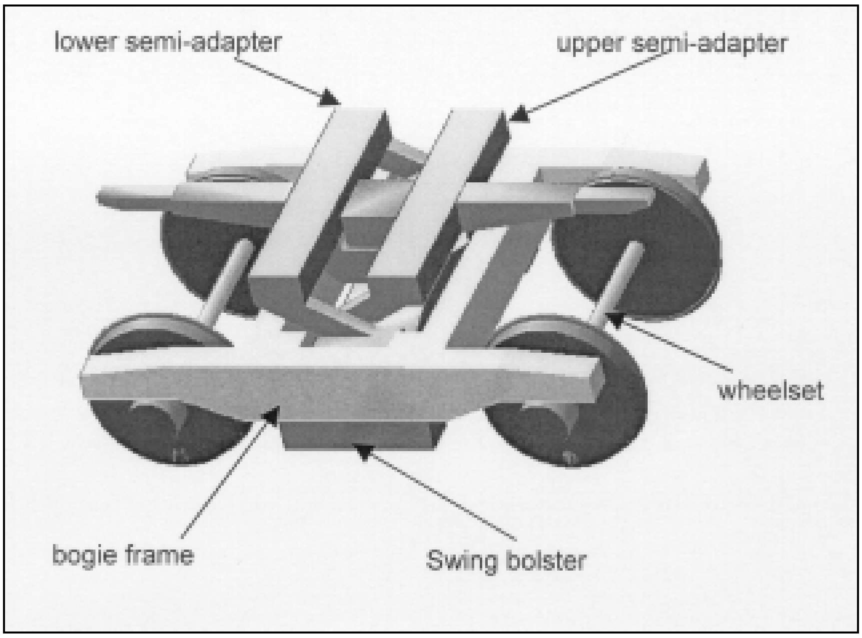


Fig.8 Intermediate bogie - Adams/View

Then the axle-box models were attached. We connected the axle-box models to the wheelsets using revolute joints, in order to allow the rotation of the wheelset around its main axis. In Table 1 all rigid elements and kinematic pairs utilised in the model of the bogie are listed. The car body is represented by rigid element in the form of a rectangular prism.

Table 1 Types of kinematic pairs utilized in bogie models

Part I	Part II	Type of the kinematic pair
Wheelset No.1	Axle-boxes No.1	Revolute joint
Wheelset No.2	Axle-boxes No.2	Revolute joint
Bogie frame	Hanger No.1	Cylindrical joint
Bogie frame	Hanger No.2	Revolute joint
Swing bolster	Hanger No.1	Revolute joint
Swing bolster	Hanger No.2	Spherical joint
Lower adapter	Swing bolster	Spherical joint
Upper adapter	Swing bolster	Spherical joint

Finally, the primary suspension elements were created. These elements are represented by force vectors acting between axle boxes and the bogie frame. Forces are proportional to the axle box displacements relative to the bogie frame. The non-linear vertical characteristics of the primary suspension is presented in Fig.9.

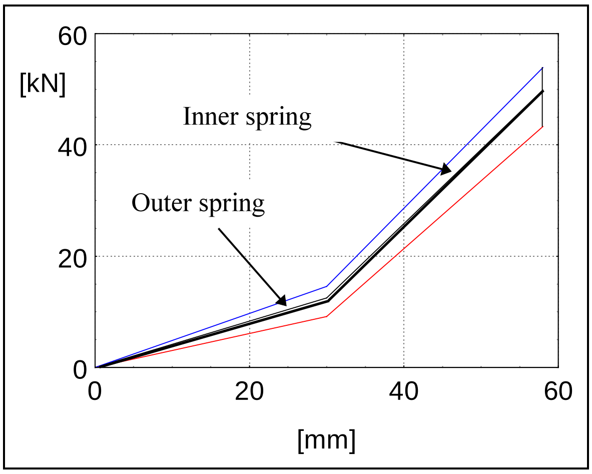


Fig.9 Nonlinear vertical characteristic of the primary suspension

The hysteresis comes from the friction dampers. The vertical suspension with friction was described with the function SGNMODE of Adams/Rail.

When the car body rolls around its longitudinal axis, the spiral springs of the side friction blocks deflect until the arm of the adapter strikes the roller. This impact is described with the function IMPACT of Adams/Rail. We approximate damping coming from the side friction blocks with linear damping, both in longitudinal and lateral directions.

3.2 The contact models

We have taken into account two type of contact models, utilising linear and non-linear contact parameters provided with RSPROF and RSGEO routines implemented into Adams/Rail. Linear contact model (Level IIa) represents the wheel-rail contact with parameters such as equivalent conicity, contact angle and Kalker's coefficients. We generated these parameters for the nominal wheel (**s1002**) and rail (**uic60**) profiles, using the option „CREATE CONTACT TABLE" of Adams/Rail.

Non linear contact model (Level III) provides 'number_of_steps' values of wheelset-rail lateral displacement in the specified range. For specified elasticity modulus, the Poisson ratio and normal load, we obtained the following data:

lateral displacement, rolling radius deviation from nominal radius, contact angle, longitudinal and lateral semi-axis of the contact patch and some other parameters. An example of calculated contact area of wheel and rail is shown in Fig.10.

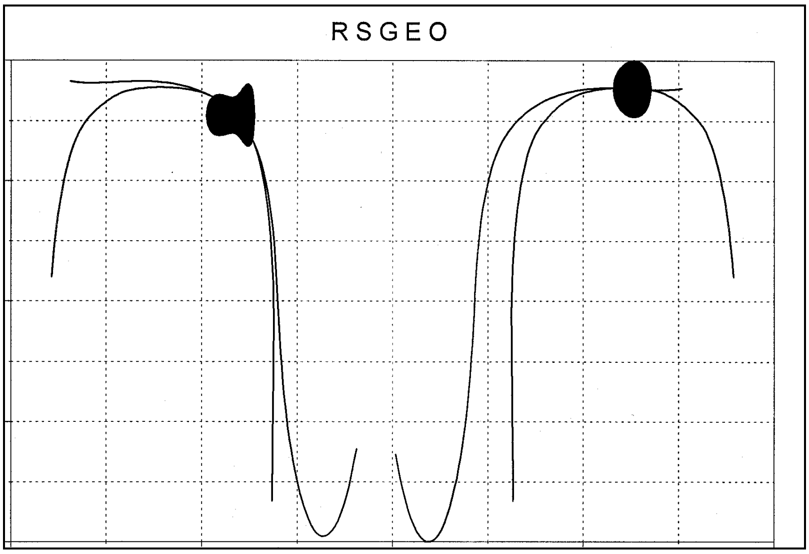


Fig.10 The real contact area between wheel and rail

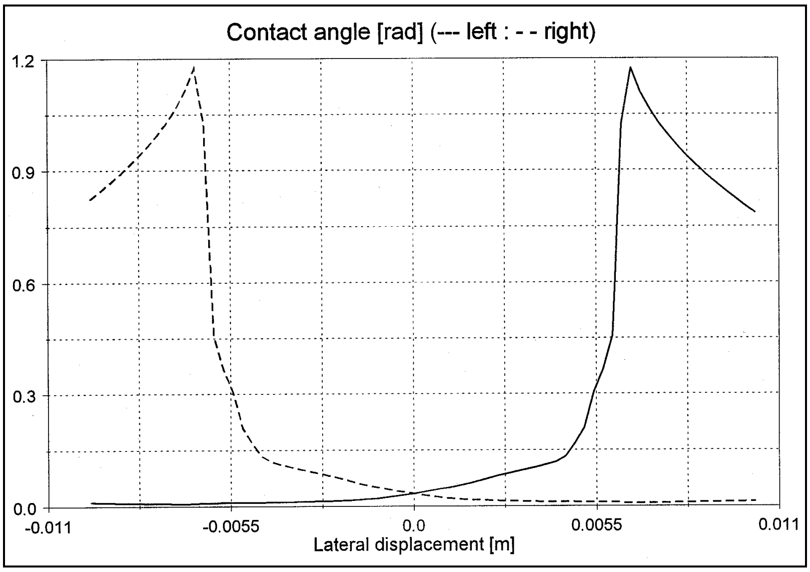


Fig.11 Contact angle in function of lateral wheelset's displacement

4 RESULTS OF SIMULATIONS

4.1 The stability study

We investigated the stability of the train by evaluating the critical speed on perfectly straight excellent track. For these calculations the contact model Level IIa was used.

As shown in Fig.12, the instability occurs at speed 65 m/s. It can be identified as the sustained lateral oscillations of the wheelsets. In Fig.13 we present one form of the wheelset instability, obtained from Adams/Rail. In the unstable state any small disturbance from the desired straight-line motion, results in increasing oscillations.

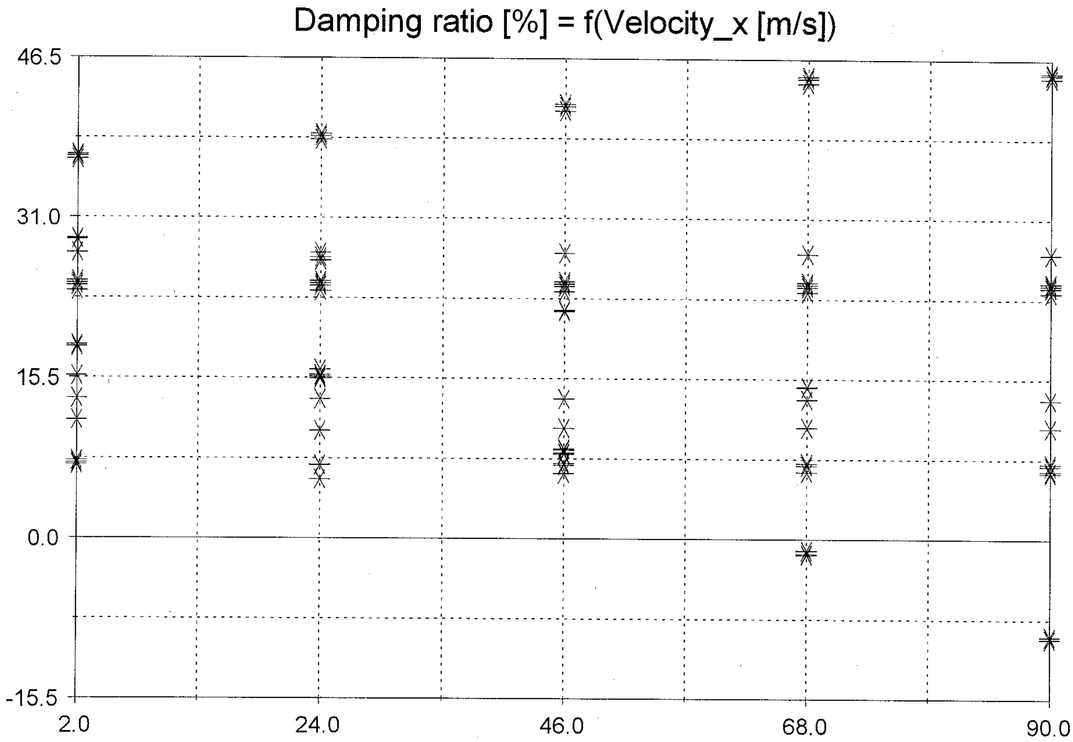


Fig.12 Damping ratio of vibration as function of the train velocity on the straight track

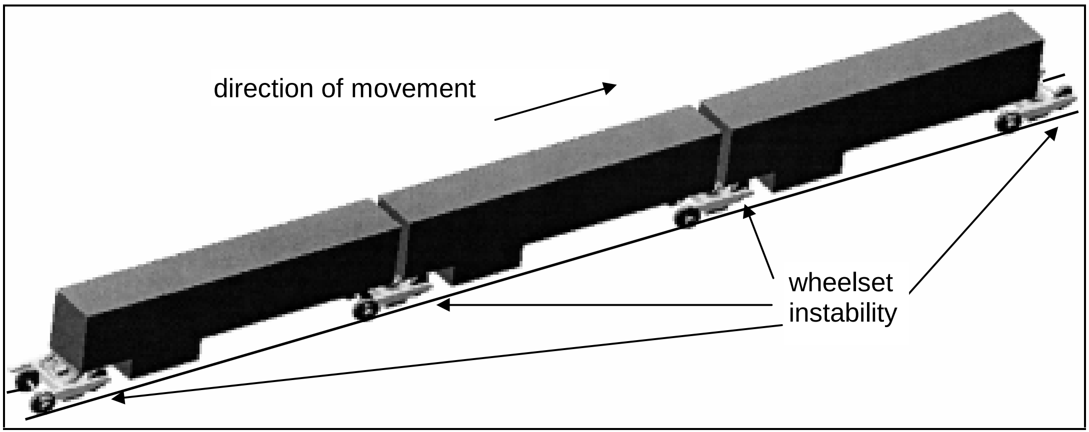


Fig.13 One of the form of wheelset instability

Performing a dynamic stability analysis we were studying the response of the system to an initial velocity, lateral to the direction of motion along the straight track. Results presented in Fig.14 were obtained for the initial velocity 0.05 m/s, when the speed of the train was 30 m/s. The model is stable at the speed V_x=30 m/s. Lateral displacements of wheelsets, bogie frames and swing bolsters are strongly damped.

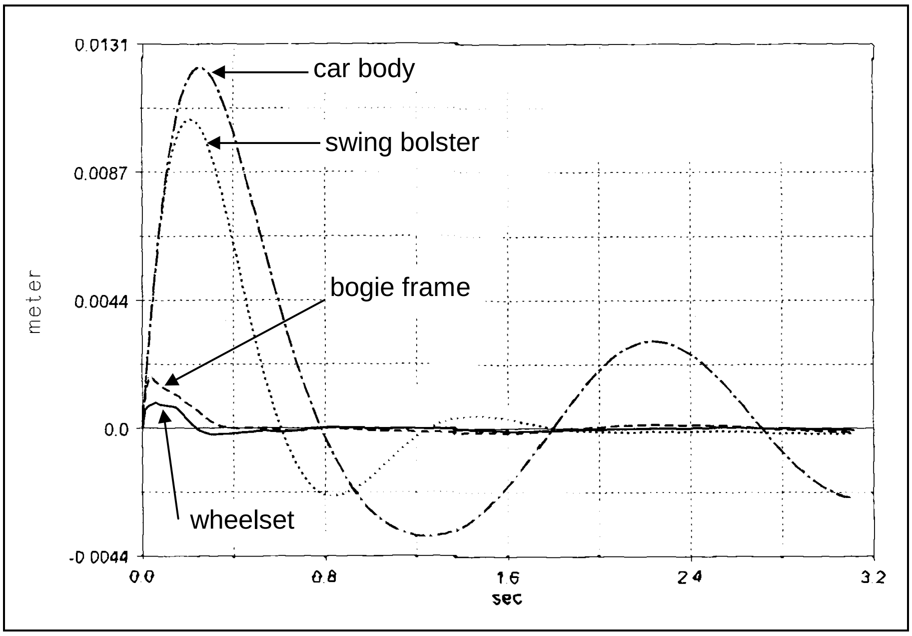


Fig.14 The lateral response of the system to an initial velocity V_y=0.05 m/s

4.2 Interaction between train model and straight track

The rails in real track have some irregularities which excite motion of wheelsets. For simulations we applied vertical irregularities obtained from the measurements on the test track - Fig.15.

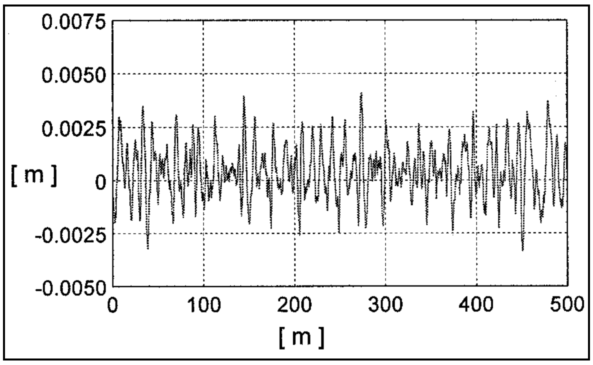


Fig.15 Vertical irregularities received from the measurements on the test track

For this task we applied non-linear contact model (Level III) of Adams/Rail. The train model was examined for the running velocity of 30 m/s, because we wanted to compare the simulation results with the measured results on the test track obtained for the prototype of the bimodal train. In diagrams below we demonstrate some time histories from simulation and measurements. In Fig.16 and 17 we present the vertical accelerations of the leading wheelset and the swing bolster of the trailing bogie.

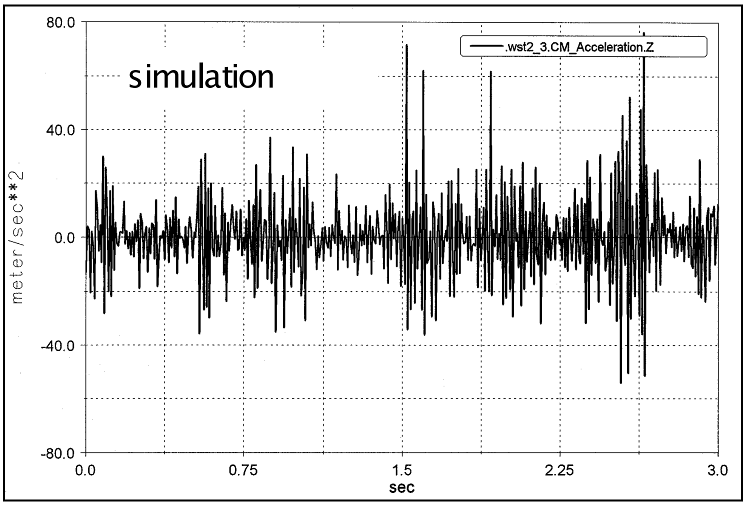


Fig.16 Vertical acceleration of the leading wheelst

Numerical values of the vertical accelerations were converted into such parameters as: RMS, MIN and MAX values. In that way we obtained for leading wheelset: RMS=12.8 m/s^2, MIN=-39.3 m/s^2, MAX=60.9 m/s^2. The measurements give the following values: RMS=7.16 m/s^2, MIN=-51.06 m/s^2, MAX=39.97 m/s^2.

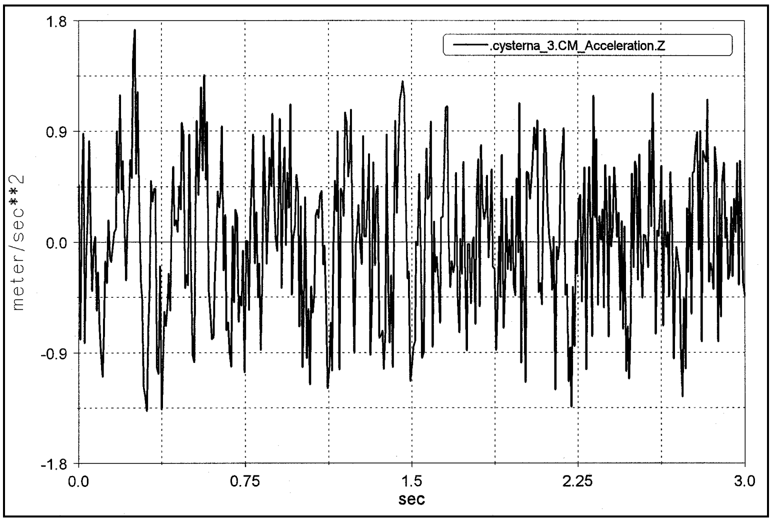


Fig.17 Vertical acceleration acting on the swing bolster

In case of the swing bolster analogous values to the results mentioned above, are: RMS=0.59 m/s^2, MIN=-0.2 m/s^2, MAX=2.22 m/s^2 from simulation and RMS=0.95 m/s^2, MIN= -3.37 m/s^2, MAX=2.23 m/s^2 from measurements.

Among simulation results it was possible to obtain some other information, for instance the longitudinal forces acting on the side friction blocks of the trailing bogie, see Fig.18.

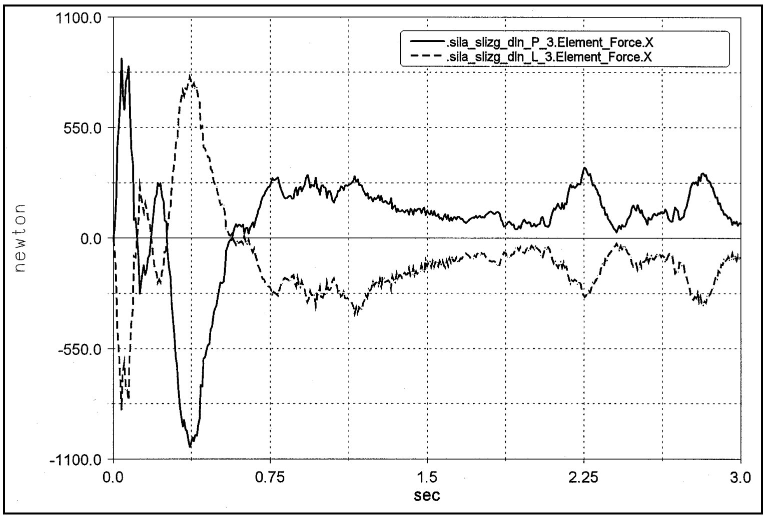


Fig.18 Longitudinal forces acting on the side friction blocks of the trailing bogie, as the result of simulation

4.3 Dynamic behaviour of the train model on the curved track

The dynamic behaviour of the train model was analysed on a perfect curved track with constant radius of curvature 2000m and without superelevation. The curve was preceded by 35m-length section of a straight track. At the beginning of run, the train was placed on the straight track segment. Some results of simulations are presented in Fig.19 to 22.

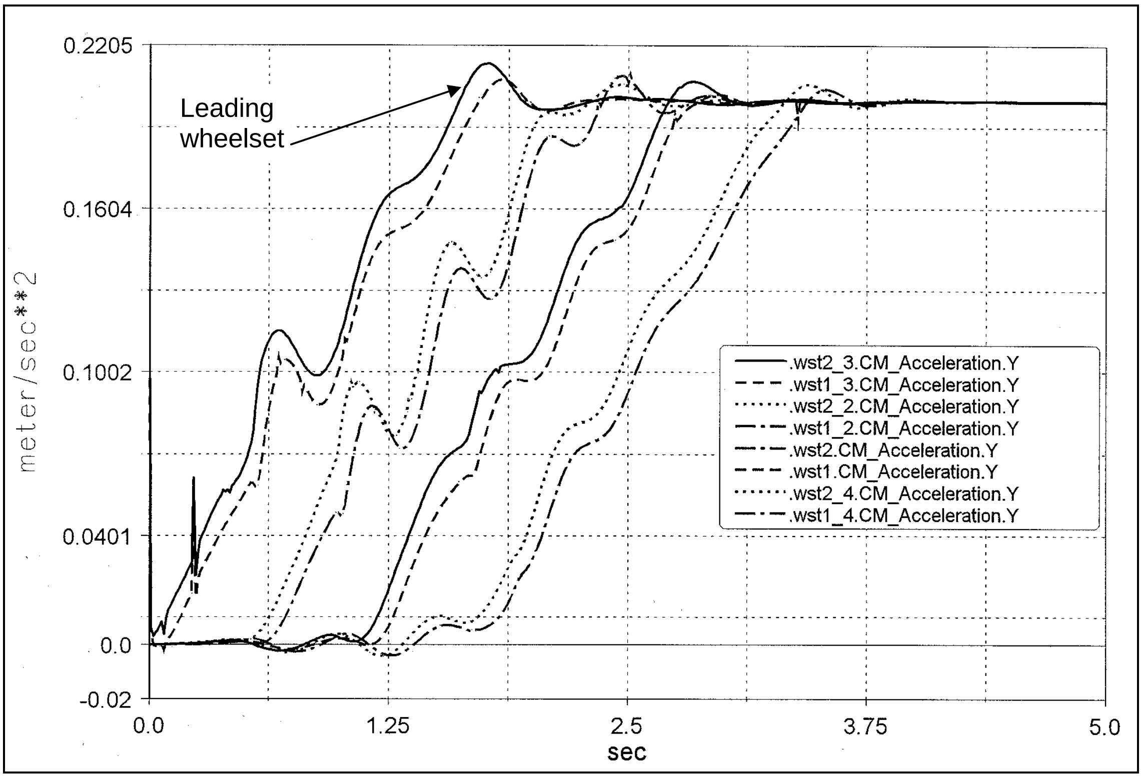


Fig.19 Lateral accelerations of the wheelsets as function of time

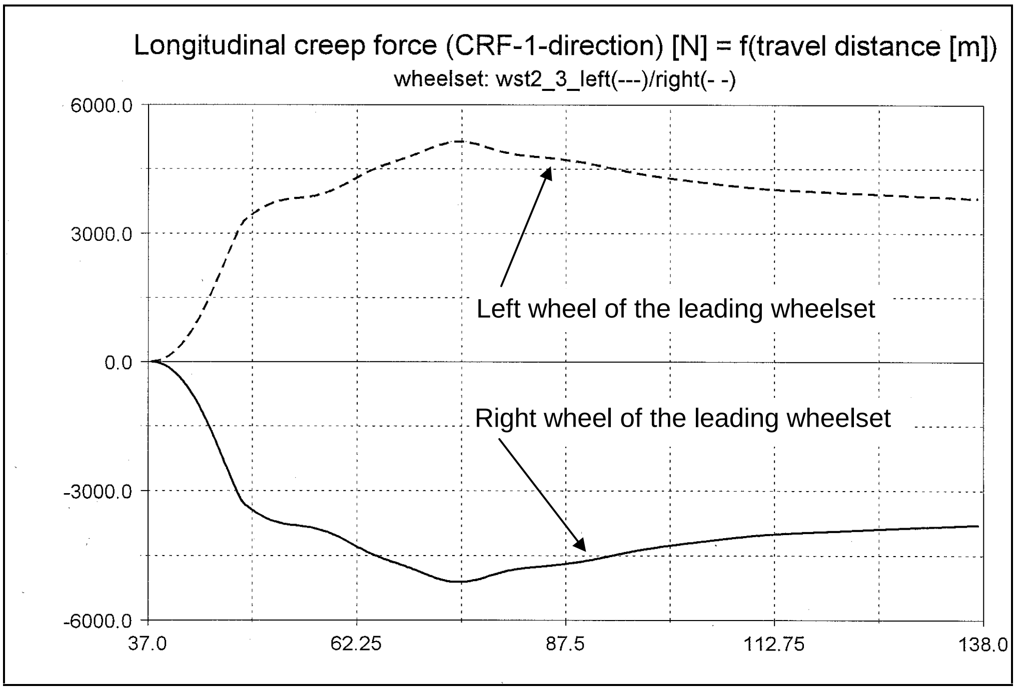


Fig.20 Longitudinal creep forces on the leading wheelset as the function of the travel distance

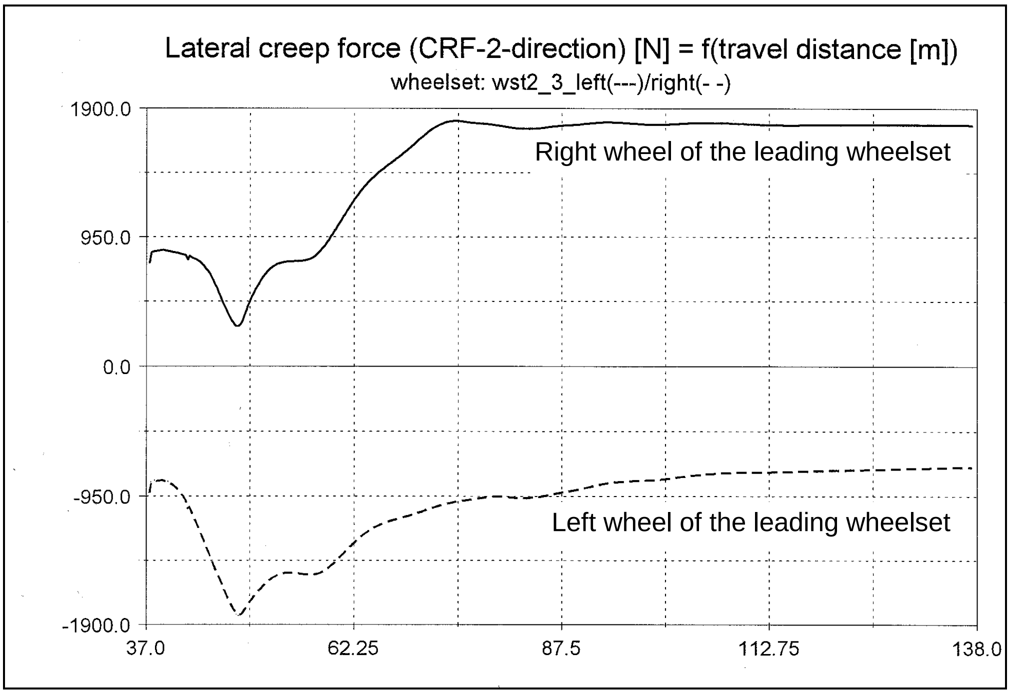


Fig.21 Lateral creep forces on the leading wheelset as the function of the travel distance

The important result of simulation for the freight bogie is the Y/Q ratio. According to the Nadal criterion, it is regarded as a measure of safety against derailment. The ratio of lateral (Y) to vertical (Q) forces for the leading wheelset is presented in Fig. 22. The value of Y/Q for the wheel should not exceed the value of 1.2.

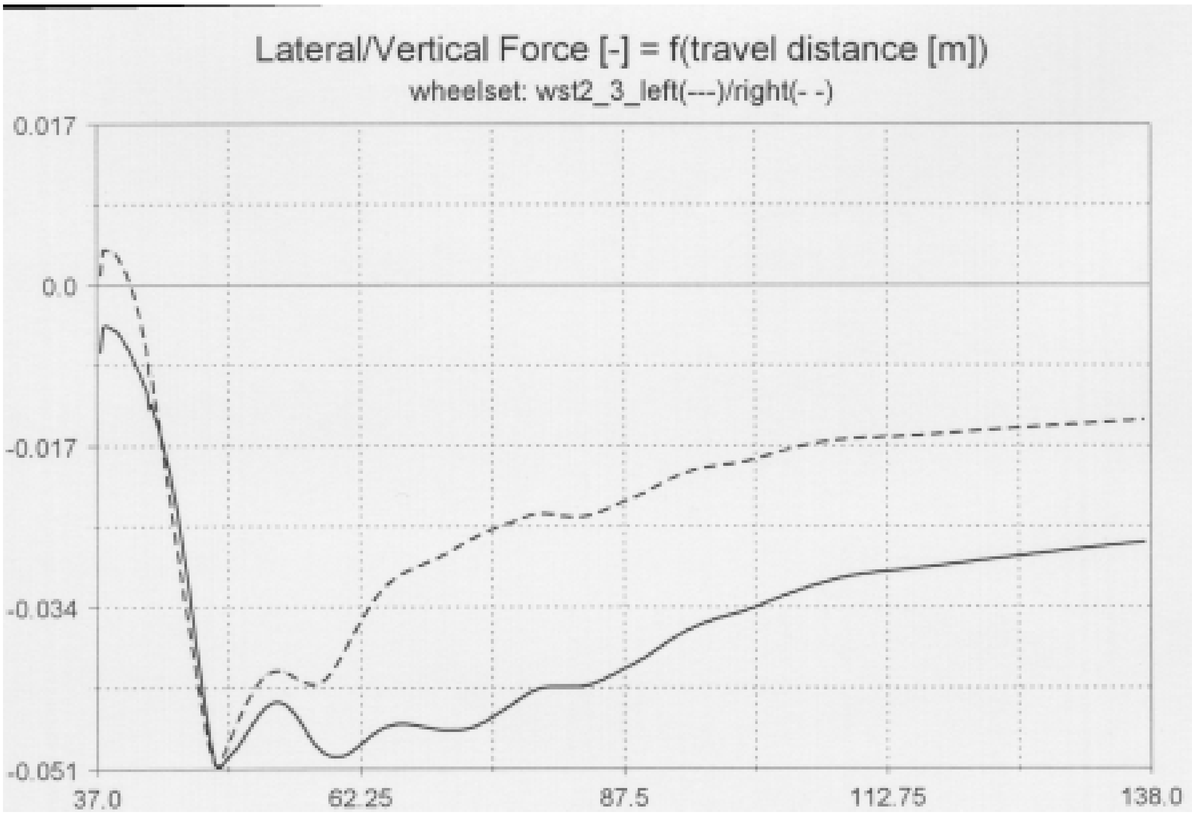


Fig.22 The ratios of lateral (Y) to vertical (Q) forces on the leading wheelset

5. CONCLUSION

The results of simulations presented above show some of the bimodal train properties on straight and curved track. The range of the investigation covers the problems associated with the analysis a the system having a large number of degrees of freedom. In such situations only the multi-body simulation tools can be really helpful.

For our study we used the licensed ADAMS/Rail 9.1 simulation package. In that way we were able to evaluate the characteristics of the bimodal prototype train in terms of lateral stability, response to the vertical track irregularities and curving behaviour.