MODELING AND DYNAMICAL ANALYSIS OF FLEXIBLE VEHICLE USING FEM AND MS APPROACH.

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1. Introduction.

The paper presents the results of modelling and dynamical analysis of a rail vehicle, which consists of flexible cisterns and rigid car bodies. The rail vehicle is an example of combined (rail and road) – bimodal transport vehicle and is based on the prototype constructed in Poznan, Poland in the middle nineties [1]. The model of the bimodal train was presented in [2] and earlier in [3], in case the effect of flexibility of the cistern was neglected and with simplified model of friction. The photography of the Polish three-unit prototype train is shown in the Fig.1.

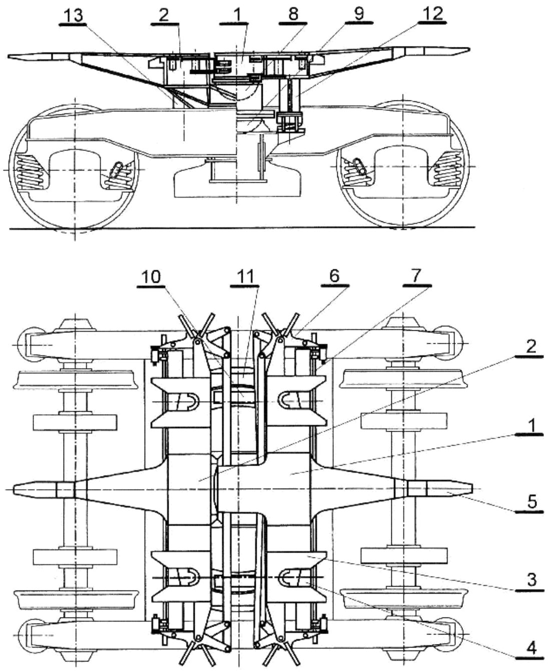
Fig.1. The view of the fragment of the bimodal train consisted of rigid car bodies and flexible cistern.
Courtesy by "Research Institute of Rolling-Stock Industry", Poznan.

It was assumed initially that the train consists of the three bimodal units in several variants – one empty flexible cistern and two rigid car bodies, three empty rigid car bodies, three loaded rigid car bodies and cistern filled with liquid and loaded rigid car bodies.

2. The details of the prototype design.

Each car body in the train is equipped [1], [2] with its own carrier structure eliminating this way railway frames. The main parts of the train are bogies, car bodies and adapters. Adapters are the light frames equipped with special locks necessary to connect car bodies to bogies. The prototype of the bimodal bogie, shown in the Fig.2. is based on the standard Y25 freight railway bogie (although with some differences).
Each of bimodal bogies possesses (Fig.2) swing bolster, which can move laterally. In the Fig.2. the intermediate bogie is shown, which connects two adjacent car bodies. The side support "3" and adapter's locks are used to mount the end of the car body on bogie frame by

the swing bolster. Vertical load from the car body is transmitted to the adapter by the side support and reaction arm and to the bogie frame with pivots (spherical joints). Side friction blocks “10” and “11” receive the load due to rolling of the car body during the motion of the train. The front and rear bogie of the train (leading and trailing) are designed in the similar way and more details can be found in [2].



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

Fig.2. Intermediate bogie.
Courtesy by “Research Institute of Rolling-Stock Industry”, Poznan.

The primary suspension of the bogie consists of two nested coil springs and friction damper. The spring characteristics have progressive character i.e. in some range of the load only outer springs are loaded in the other both outer and inner springs work.
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 load from the car body to the bogie frame and then to the wheelsets.
The prototype of the flexible cistern is shown in the Fig.3.

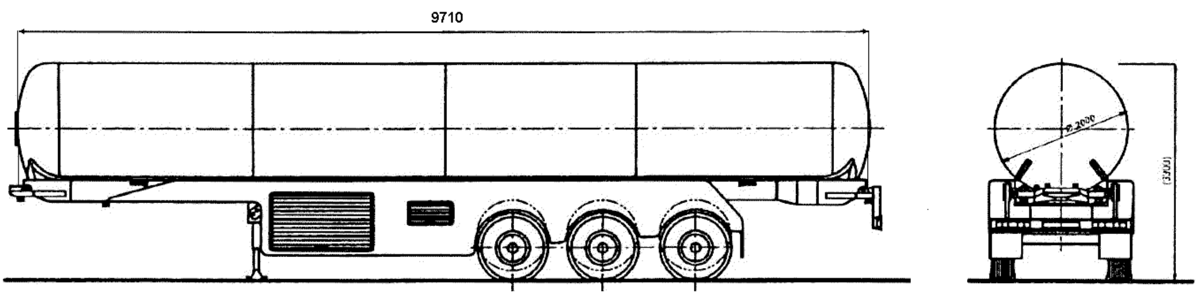


Fig.3. The cistern for liquid transport.

Courtesy by “Research Institute of Rolling-Stock Industry”, Poznan.

3. The MS and FEM model of the train.

The model of the train was built in the ADAMS 11 environment. The model of the intermediate bogie is shown in the Fig.5. Exemplary spring characteristics in vertical direction are given in the Fig.4.

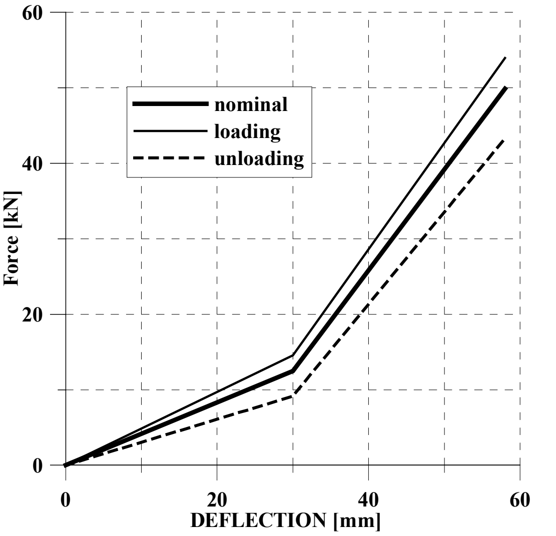
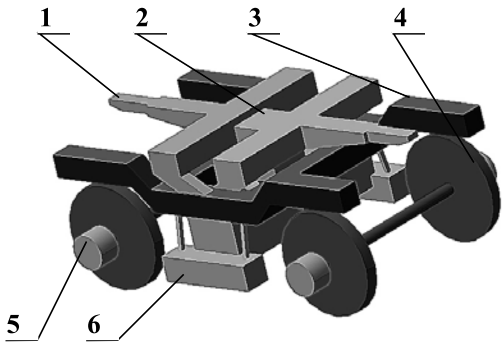


Fig.4. Primary (vertical) suspension spring characteristics.



1 – Lower adapter, 2- upper adapter, 3 – bogie frame, 4 – wheelsets, 5 – axle boxes, 6- swing bolster.

Fig.5. The ADAMS model of the intermediate bogie.

The friction forces in pivots were modelled using model of friction for spherical joint implemented in ADAMS, and separately in more simplified form, without transition phase using arctg function. The cistern was modelled in ANSYS environment using SHELL 43 elements. The meshing of the cistern is shown in the Fig. 6.

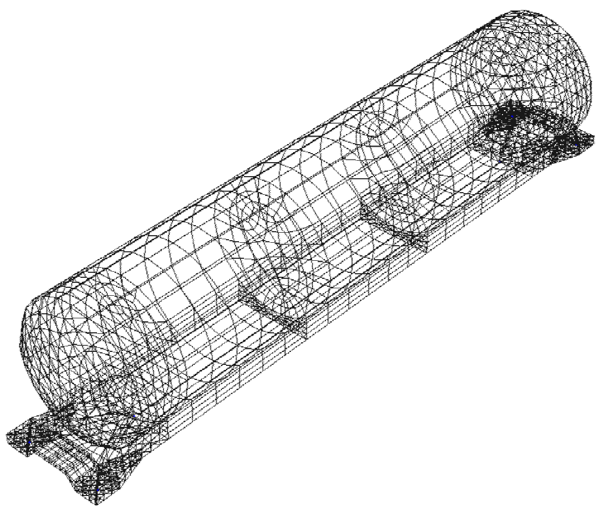


Fig.6. Meshing of the cistern.

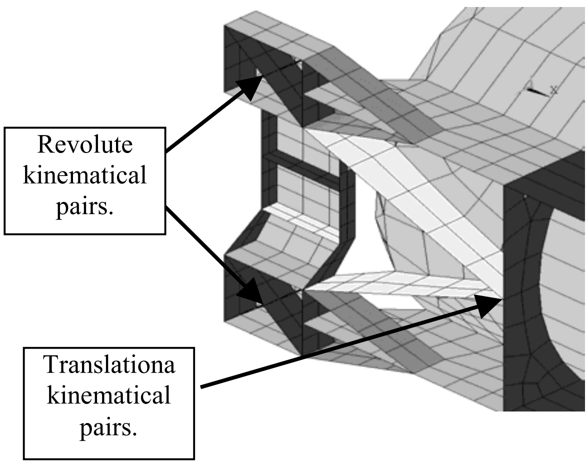


Fig.7. The interface points between cistern and adapters.

Cistern is fixed to the bogie using reaction arm and adapter locks. They were modelled using interface parts and revolute and translational joints (Fig.7). The model of friction was based on the ADAMS 11 implementation. Static and dynamic friction and transition phases are included using ideas given in [4]. The boundary DOFs during Craig-Bampton reduction of cistern substructure were chosen in the nodes where kinematical pairs between cistern and adapters were placed. The number of modal coordinates was chosen after many numerical experiments and was equal to 100 in majority of numerical simulation. The damping coefficient were taken as 1% of the critical damping for mode shapes with frequencies below 500 Hz, 10% for frequencies between 500 and 1000 Hz and 100 % above.
The mnf file of meshed empty cistern was generated using ANSYS environment and macro utility given in the package. For introductory simulation of the liquid pressure and dynamics influence, provided the cistern is fully filled (the sloshing effect is neglected), the distributed load of the pressure was translated to node forces using macro given in [5] and included into mnf file using ADAMS mnfload utility.
The contact forces between rail and wheels were modelled using nonlinear wheel-rail contact model based on wheel-rail profiles, which allows three-dimensional multi-point contact description [6]. The influence of various track parameters on the train dynamics was investigated by using different track parameters (curvatures, cant angles, irregularities) during simulation.
The view of the train model consisting of cistern and two rigid car bodies and separately view of the cistern are shown in Fig.8 and in Fig.9, respectively.

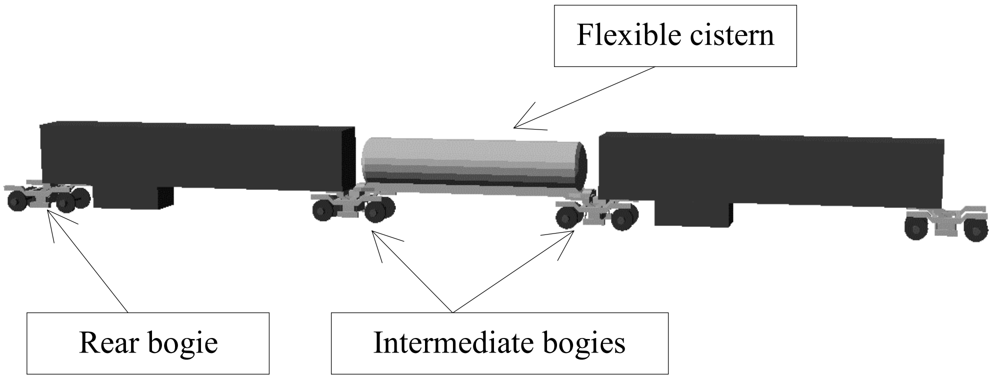


Fig.8. Train assembly

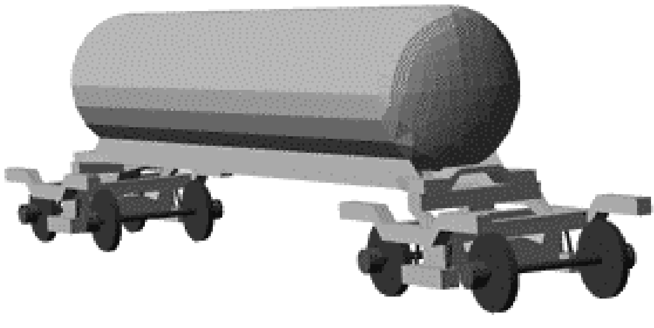


Fig.9. The ADAMS view of the flexible cistern model.

4. Results of the ADAMS/ANSYS simulation.

During simulation different kinds of dynamical analysis were performed using different values of track parameters, different kinds of friction models, the cases when car bodies are fully loaded or they are empty, various combinations of the train assembly etc. Since force characteristics were also analysed the integration algorithms with constraints stabilisation (SI2) were applied in some cases during numerical analysis.
As a typical the dynamical analysis of the train with flexible cistern (Fig.8) was chosen to presents some results. The train consists of two empty rigid car bodies and flexible cistern. The dynamic behaviour of the train was analysed on the curved track with the curvature equal to 10^{-3} m proceeded by the 80 m length section of the straight track.
The initial velocity was equal to 30m/s (108 km/h) and the time of simulation equal to 10s for that length of the rail.
In the Fig.10 the differences between two models of friction torques are shown. In the first model friction forces in the pivots are calculated using ADAMS 11 model of friction (model 2). In the second case friction is calculated under assumption that only z coordinate of the friction torque in the pivot has a significant influence on the train dynamics (model 1) and x component can be neglected (only dynamic friction was included in this case). This restrictive assumption which was taken in the previous simulation [2], [3] leads to different results compared to ADAMS friction. Absolute values of x component of the friction forces obtained from ADAMS model of friction are magnitude of z component and can not be omitted.

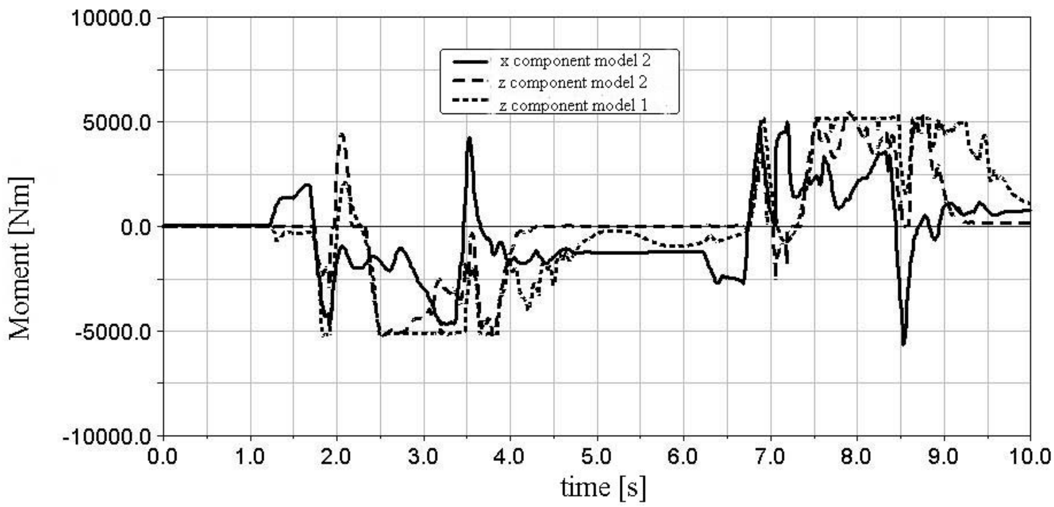


Fig.10. Moment of the friction forces (x and z components) in case the friction is modelled with ADAMS model of friction and simplified model of Coulomb friction without creep phase.

Compared to model of the train with rigid car bodies the valuable results can be obtained from the analysis of reaction of the constraints imposed by revolute and translational joints between cistern and adapters. They can help to evaluate loads in construction nodes. In the Fig.11 the values of the longitudal and lateral reaction forces are obtained from dynamical simulation with SI2 type algorithm of numerical integration.
The important result of simulation for the freight bogie is the Y/Q ratio (derailment quotient). The value of derailment quotient for the wheel should not exceed the value of 1.2. According to the Nadal criterion, it is regarded as a measure of safety against derailment. The ratio of lateral to vertical forces for the leading wheelset is presented in the Fig.12.

The important factor which was evaluated in the ANSYS environment during simulation of the train were the stresses and particularly stress concentrations in the cistern. However it should be pointed out that liquid effect was modelled only as a vertical hydrostatic pressure which can be considered only as a very simplified (introductory) model of liquid-cistern contact.

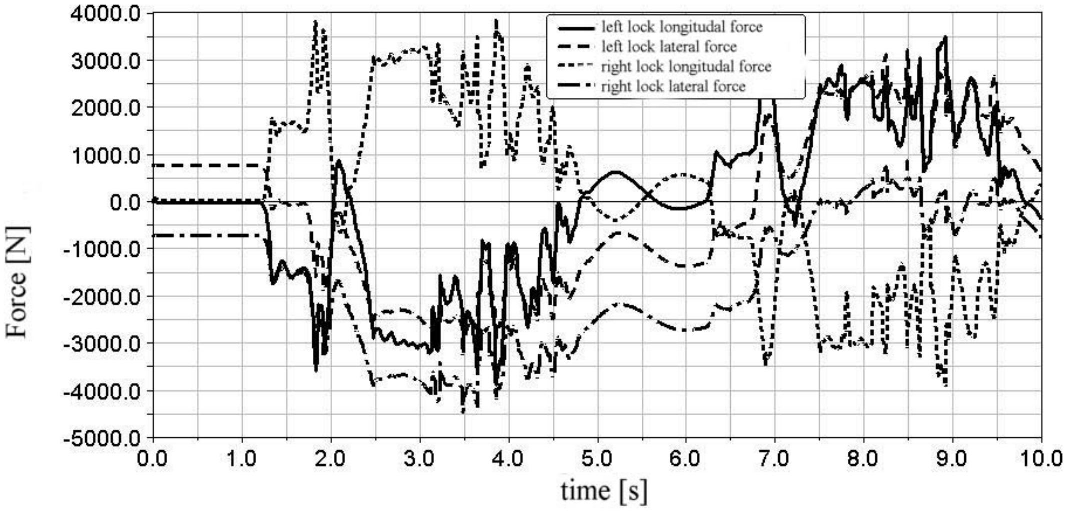


Fig.11. The forces in adapters locks (left and right) in the intermediate bogie during the motion on the curved track.

The stress analysis of the empty cistern during motion of the train seems to be less interesting, since the levels of stress are low and only places of stress concentration could be used for further analysis.

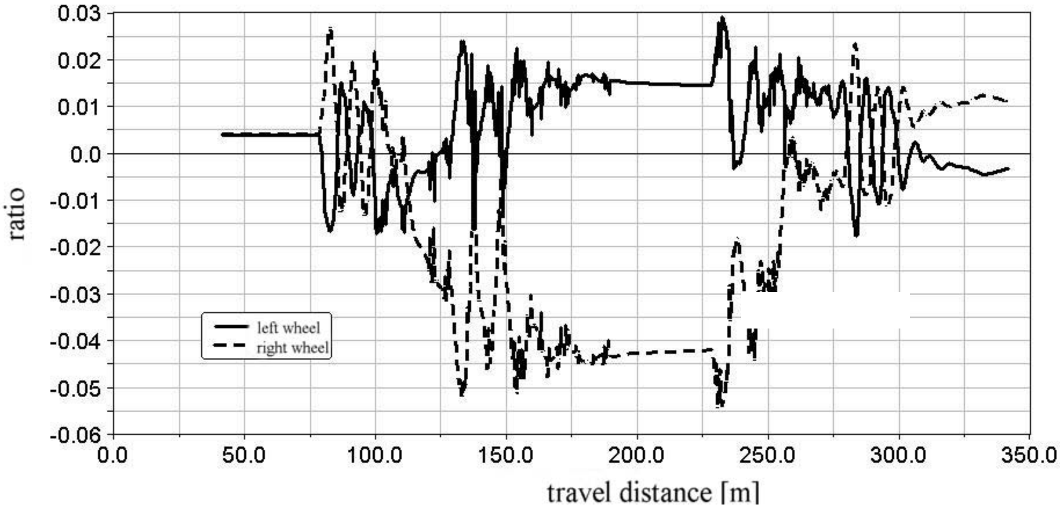


Fig.12. The ratio of the lateral to vertical forces as a function of travel distance.

In the Fig. 13. the stress distribution (Von Mises) of the cistern for the time equal to 11 s, is presented obtained during dynamical analysis of the fully loaded car bodies and with simplified model of cistern filled with liquid (fuel) . The stress recovery was obtained using ADAMS export FEA utility and next the ANSYS transient analysis (using the equilibrium methods the similar results were obtained).

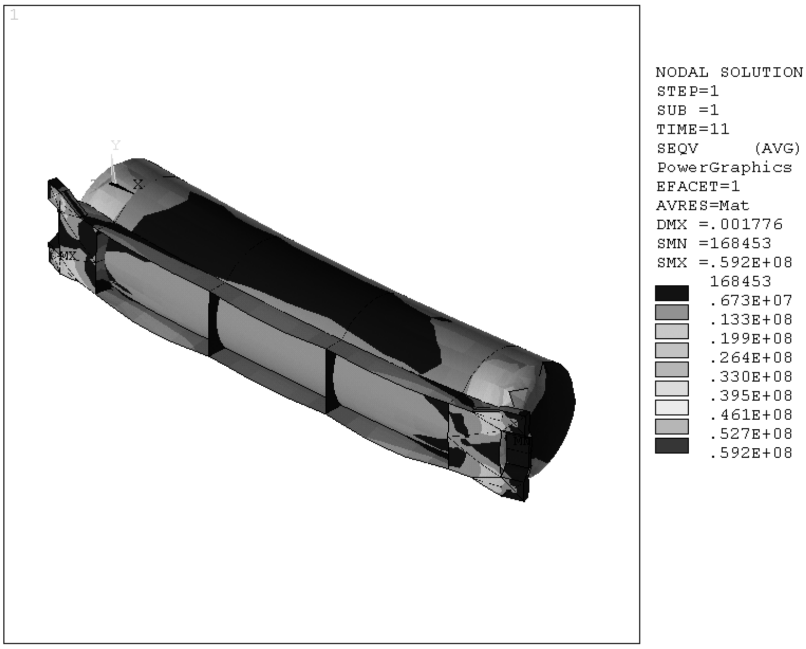


Fig.13. Stress distribution in the cistern for the time=11s and initial velocity =20 m/s.

6. Conclusion.

The results of the dynamical analysis of the bimodal train show some properties of the prototype design, which can be used, in the further process of the train design and in the analysis of the properties of the real train. Some of the results were validated with experimental measurements. Mixed MS and FEM environment proved to be an effective tool for the dynamical analysis of the vehicle consisting of rigid and flexible bodies.

Acknowledgements.

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7. References.

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