MODELLING AND SAFETY EXAMINATION OF THE LONG BIMODAL TRAIN ON CURVED TRACK USING ADAMS/RAIL

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1. INTRODUCTION

The bimodal transport is a subsystem of the combined transportation system, which integrates shipment of goods on road and rail without transhipment when changing from road to rail mode and vice versa. Bimodal transport combines the requirements of road and rail transport and completely eliminates vertical movements of loading units during terminal operations (Fig.1).

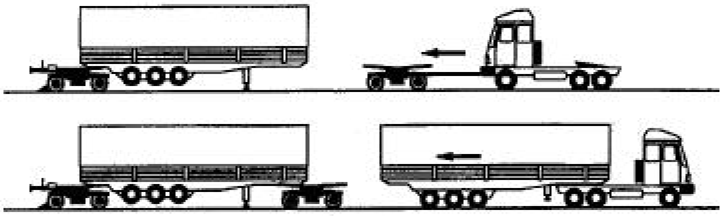


Fig.1. The principle of compose the bimodal train

The development of the bimodal train in Poland started several years ago. In 1994 for the first time the prototype was displayed in Poznan during the International Mess. The scheme of the Polish three-unit prototype bimodal train is shown in Fig.2.

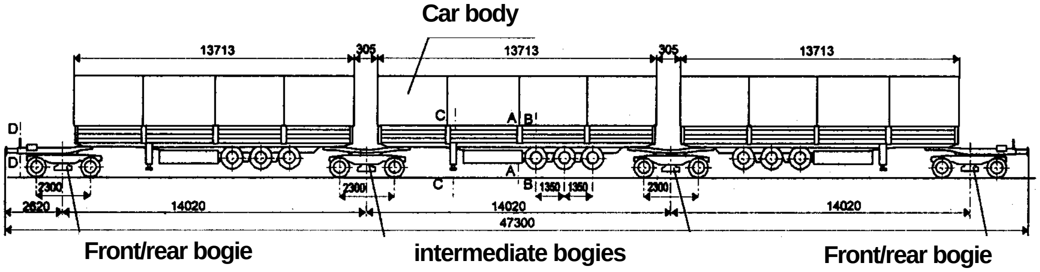
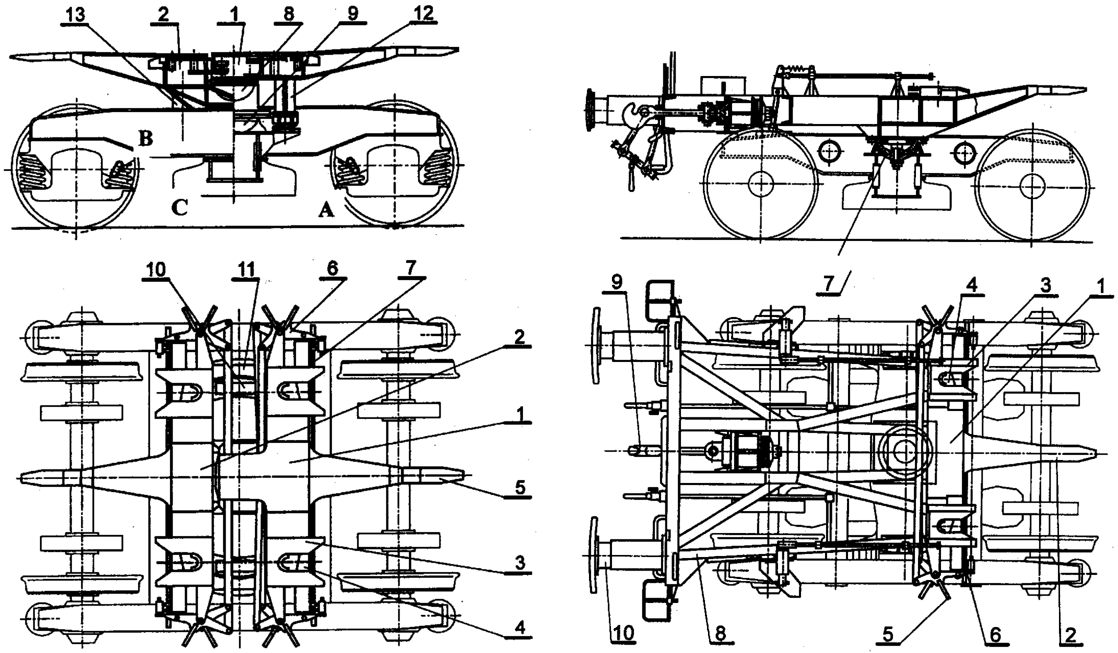


Fig.2. The scheme of the Polish three-unit prototype bimodal train,
source „Research Institute of Rolling-Stock Industry in Poznan"

The lack of information concerning safety of bimodal train longer than three wagons [5] was the main motivation for modelling and investigation of long bimodal train on the curved track. Loading units (in our case semi-trailers) form the train after clutching through adapters to bogies. At the front and at the end of the train there are front/rear bogies equipped with single adapters. All the other units are connected through adapters to the intermediate bogies. Each intermediate bogie carries 2 semi-adapters, which allow in relative yaw, roll and pitch of the adjacent units.

2. ELEMENTS OF THE TRAIN

The real train structure consists of railway freight bogies and bimodal car bodies (semi-trailers) shown in the Fig.2. Each car body is equipped with its own carrier structure. In that way railway frames in the train are eliminated and the train consists of only bogies, car bodies and adapters. Adapters are designed as the light frames, equipped with special locks necessary to connect body with the bogie. Design of the bimodal bogie is based on the Y25 freight railway bogie with frictional dampers, but in some details it differs from standard design. Each bimodal bogie possess swing bolster, which can move laterally to the longitudinal axis of the bogie frame. The adapters of the intermediate and rear bogie are shown in the Fig.3. Intermediate bogie connects two adjacent car bodies [3], [4].



(a) (b)

Fig.3. Intermediate (a) and Rear (b) Bi-modal Bogies,

source „Research Institute of Rolling-Stock Industry in Poznan"

Side supports „3" and adapter's locks „4" are used to mount the end of car body on the bogie frame „B", utilizing the swing bolster „C". Reaction arms „5" cooperates with the car body nest, that is placed at the bottom end part of the car body (Fig.3a). 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. Rear bogie has only single adapter „8" with coupling screw „9" and the end stops „10" (Fig.3b). The other equipment of this bogie is similar to the intermediate bogie.

Primary suspension of the bimodal bogie consists of two nested coil springs “2”, “3” and frictional damper “5” - Fig.4. The inner spring „2” is weighted down only when the vehicle is laden. Primary friction damping is provided with hornguides and is varied with load via an inclined Lenoir Link „6”. The damping in the bogie suspension is caused by friction between friction surfaces of frictional dampers. 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 preload force, applied by the Lenoir Link, makes the primary suspension very stiff longitudinally. The dynamical response of this type of vehicle is extremely non-linear.

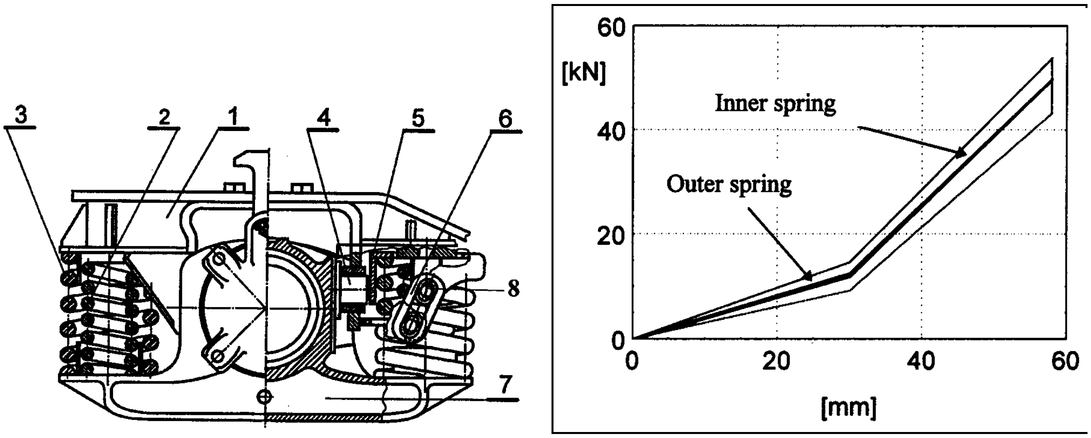


Fig.4. Primary Suspension and its non-linear vertical characteristic

Secondary suspension is realised as a swing bolster, connected to the bogie frame by two pair of hangers. For each of the bogie there is a centre pivot’s nest, placed on the swing bolster. The spherical pivot and adapter transmit vertical load from the car body to the bogie frame, and then to wheelsets.

3. SIMULATION MODEL OF THE LONG BIMODAL TRAIN

Simulation of the train motion was carried out in ADAMS/RAIL 11.0 environment. The model of the train consists of 21 two-axle freight bogies and 20 car bodies shown in Fig.5. Total length of the train is equal to 280 meters.

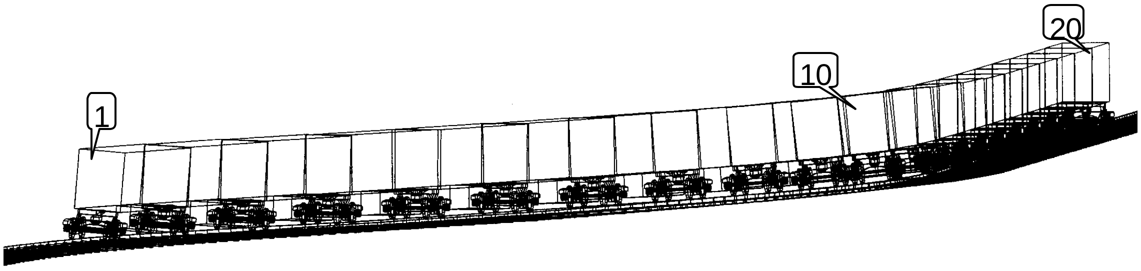


Fig.5. Simulation model of the 20-units bimodal train on the curved truck

The primary suspension elements are represented by force vectors acting between axle boxes and bogie frame. Forces are proportional to the axle box displacements relative to the bogie frame [6]. Non-linear vertical characteristic of the primary suspension is presented in Fig.4. The hysteresis comes from the frictional dampers.

When the car body rolls around its longitudinal axis, the spiral springs of the side friction blocks deflect as long as the adapter's arm strikes the steel bump stop. This effect is described using IMPACT function of Adams/Rail. Simulation model considers linear friction forces acting on the surfaces of the side friction blocks, in longitudinal and lateral directions.

The simulation model of the long bimodal train consists of 230 moving parts, 22 cylindrical, 84 revolute and 61 spherical joints. Total number of degrees of freedom is equal to 441.

The general non-linear wheel-rail contact model, implemented in ADAMS/RAIL, which allows for three-dimensional multi-point contact description for real wheel (**s1002**) and rail (**uic60**) profiles, was used during simulations.

The train model was examined on the rigid, smooth curved track shown in Fig.6. Whole track was divided into sections: straight track (345 m), right/left orientated transition curve (50 meters with curvature =1/ 320 and cant angle 0.1), right/left orientated arc (20 meters with curvature =1/ 320 and cant angle 0.1), middle part of straight track (50 m).

Fig.6. The track lay-out

4. CRITERION OF SAFETY AGAINST DERAILMENT

For the safety examination of the long bimodal train against derailment Nadal and Weinstock criteria [2] were used. A flange climb derailment situation occurs when lateral to vertical force ratio Y/Q reach the maximum value for single wheel. This criterion, originally suggested by Nadal, is used by many railroads throughout the world. Nadal's equation is based on the equilibrium of forces on the inclined plane of contact between wheel and rail. The point of derailment occurs if the sum of the vertical components of the normal and tangential forces is sufficient to support the vertical load on the wheel. The limiting Y/Q is a function of the flange angle δ and the flange coefficient of friction μ (in our case μ equal to 0.4):

$$\frac{Y}{Q} = \frac{\mathrm{tand} - \mu}{1 + \mu \mathrm{tand}} \tag{1}$$

More realistic approach proposed Weinstock. His flange climb derailment criterion based not only on a single wheel Y/Q, but also on the Y/Q of the second wheel of the wheelset. The sum of the absolute values of the Y/Q for two wheels on a common axle should not exceed the sum of Nadal's criterion and the coefficient of friction:

$$\frac{Y}{Q} = \frac{\mathrm{tand} - \mu}{1 + \mu \mathrm{tand}} + \mu \tag{2}$$

5. RESULTS

Calculations were carried out in ADAMS/RAIL 11.0 [1] environment using Pentium III 500/512 MB RAM platform. Declared time of the run was 40 seconds, with 500 output steps. Each car body of the train was loaded in 100% (total weight of the single car body was 34000 kg).

According to general principles the maximum train velocity should not exceed a limit of 20 m/s. The simulation was started with constant velocity of the train equal to 20 m/s. After three seconds the braking torque (8000 Nm), shown in Fig.7, was applied to each wheelset axes of the first ten wagons. The next ten wagons were not braking. After 40s velocity of the train decreased to 5 m/s (see Fig.8).

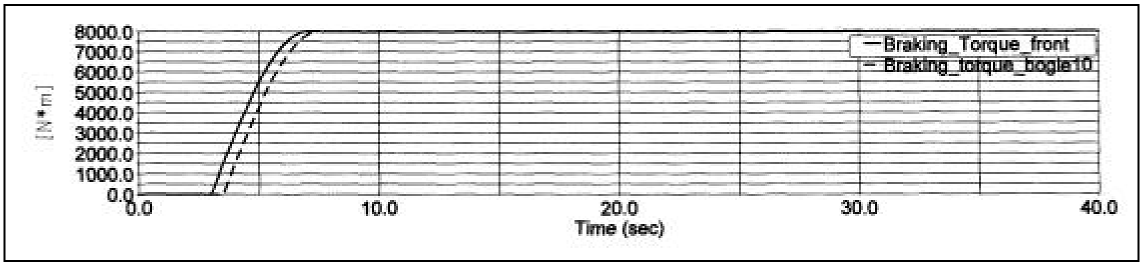


Fig.7. Braking torque applied to wheelset axes

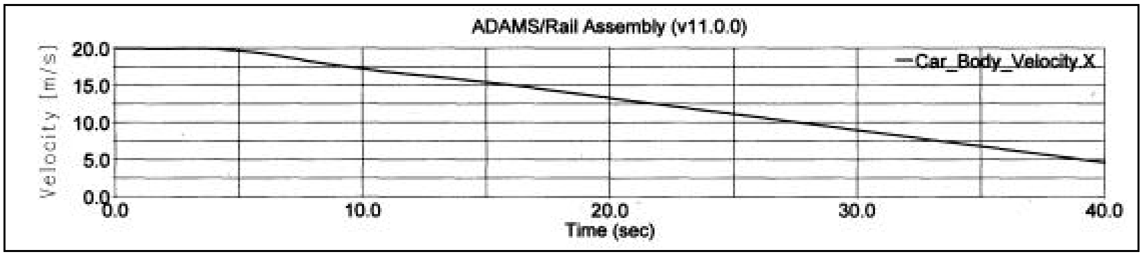


Fig.8. The train velocity

Simulation results provided many interesting information concerning accelerations acting on the bodies. In Fig.9 negative accelerations acting on the 1st, 10th and 20th body in longitudinal direction can be observed.

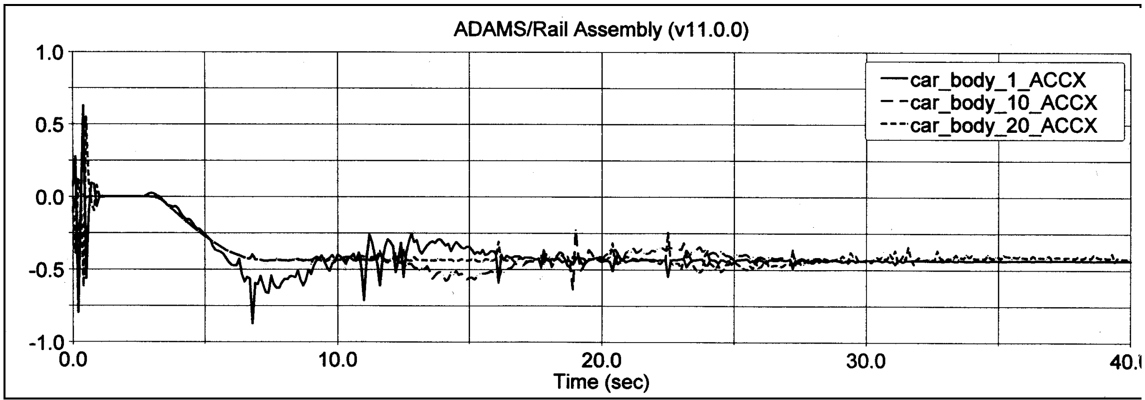


Fig.9. Accelerations [m/s^2] acting on the 1st, 10th and 20th car body in longit. direction

At the same time car bodies move with lateral accelerations which are nearly three times higher than in longitudinal direction (Fig.10). It should be pointed out that obtained levels of accelerations are acceptable for the train and the track cases described above.

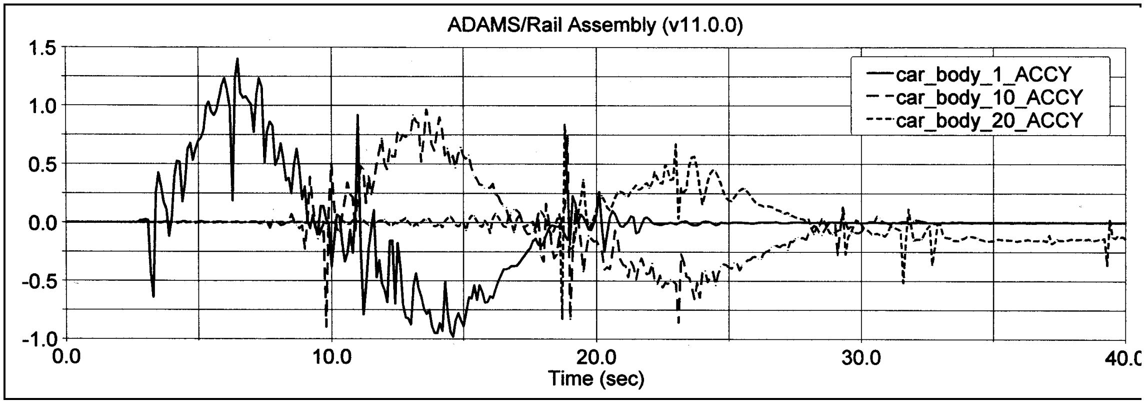


Fig.10. Lateral accelerations [m/s^2] acting on the 1st, 10th and 20th car body

Since braking torque was applied to axles of first ten bogies, there are differences in character of creep forces, arising between rails and wheels. In Fig.11 changes of longitudinal creep forces for left and right wheel of the braking leading wheelset in front bogie are shown. In our case these forces are different for each wheel.

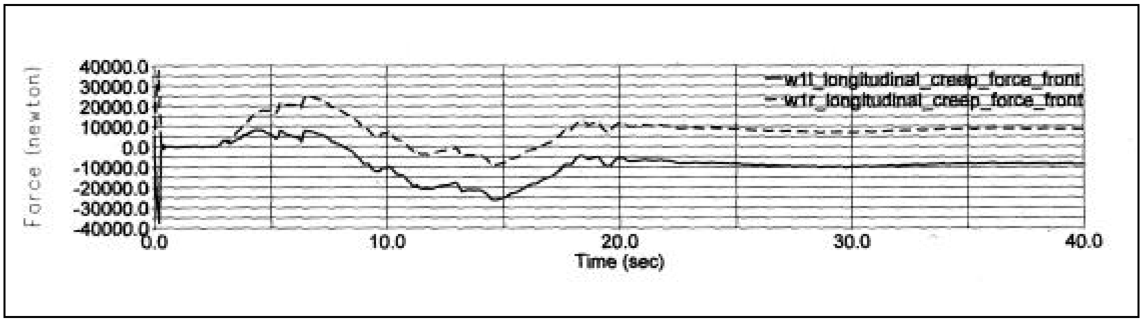


Fig.11. Longitudinal creep forces for left and right wheels of the leading wheelset (braking) in front bogie

Analogous results (but now without braking) for wheels of the leading wheelset in rear (last) bogie of the bimodal train are shown in Fig.12. Longitudinal forces are exactly the same in both cases.

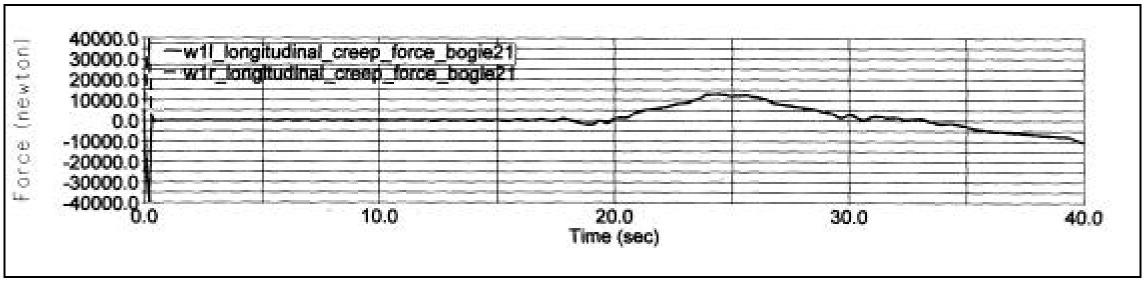


Fig.12. Longitudinal creep forces for left and right wheels of the leading wheelset (not braking) in rear bogie

The most important was the question about safety of the long bimodal train. It was found that the greatest contact angles occur on the wheels of the leading wheelset in front bogie (see Fig.13). That is the reason we specially focused on the leading wheelsets.

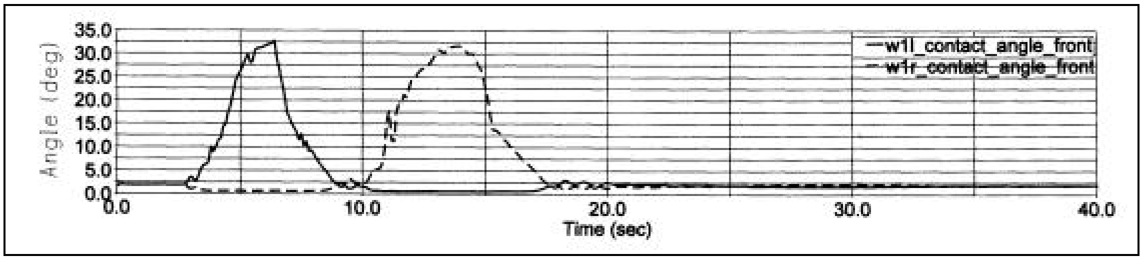


Fig.13. Contact angles on the wheels of leading wheelset in front bogie

Results presented in Fig.14 concern left wheels of leading wheelsets in front, 10th and rear bogies.

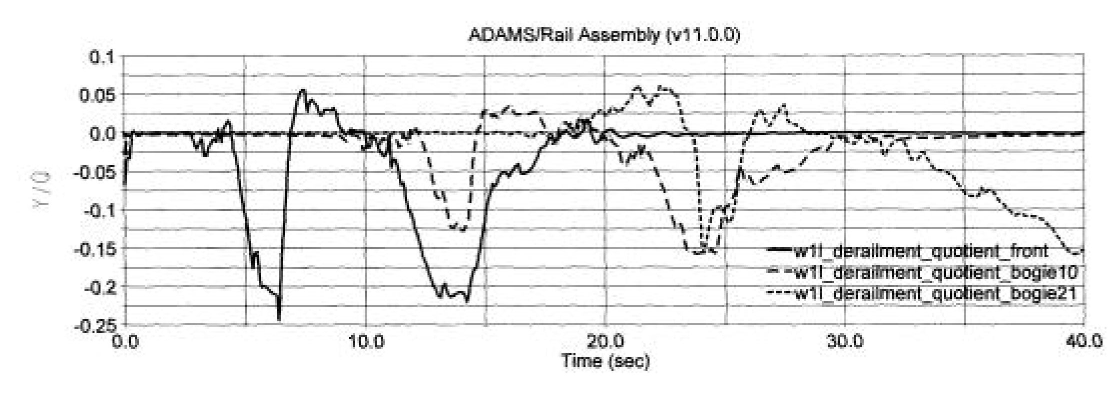


Fig.14. Values of Y/Q for left wheels of leading wheelsets in front, 10th and rear bogies

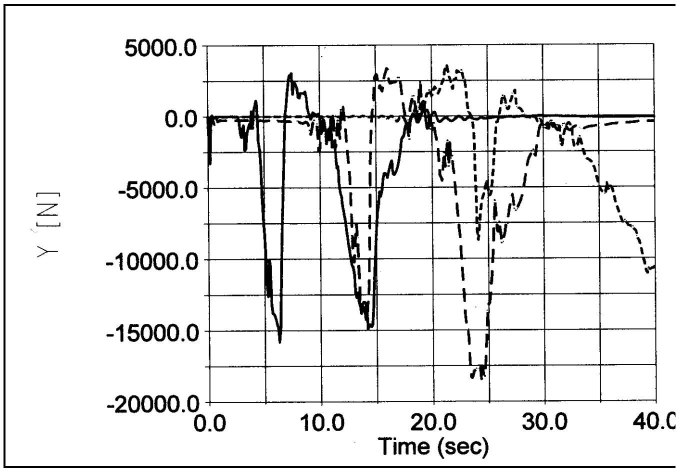


Fig.15. Guiding forces acting in contact area (correspond with Fig.14)

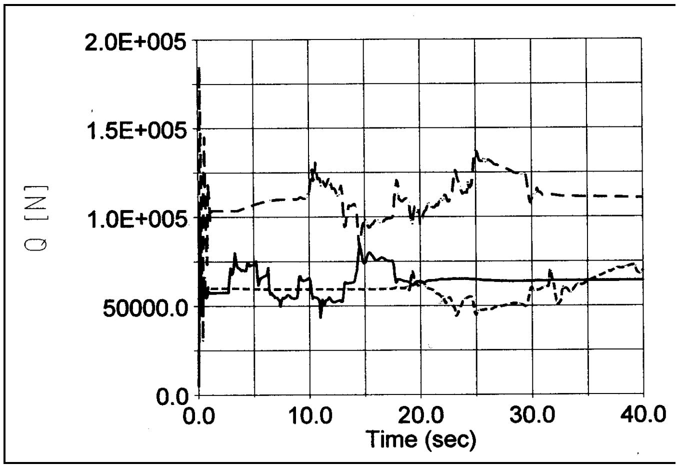


Fig.16. Vertical forces acting in contact area (correspond to Fig.14)

The sign of the Y/Q results from the sign of guiding and vertical forces acting in contact area (compare Fig.15 and Fig.16).

Since non-linear contact model was used in ADAMS/RAIL simulations, real geometry of wheel and rail was considered and real contact angles, angles of attack, spin, longitudinal and lateral creepages were taken into account. As a consequence information concerning Y/Q ratio obtained from ADAMS simulations can serve as a reliable source of information about safety of the long bimodal train on curved track.

To be sure, that Y/Q level is satisfactory, these results were compared to the values calculated from equation (2). According to the quoted Weinstock's criterion we can see, that limitation of Y/Q ratio depends on contact angle and coefficient of friction. In Fig.17 absolute values (line "1") of Y/Q for left wheel of leading wheelset in front bogie, obtained from equation (2) and the sum of absolute values Y/Q for two wheels of the same wheelset (dashed line "2") obtained from ADAMS are compared. We can see, that formal conditions are fulfilled, because the sum "2" does not exceed the limit "1".

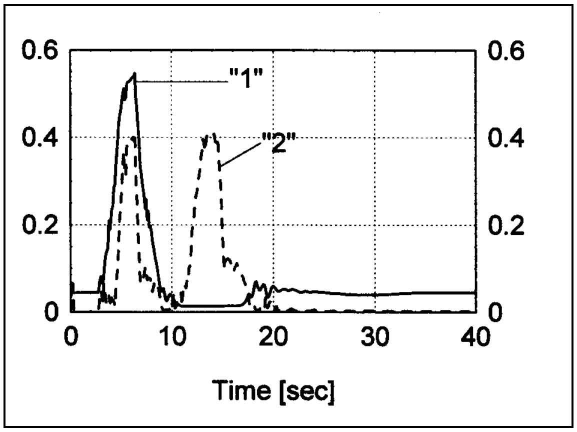


Fig.17. Comparison of absolute values Y/Q

"1" – Weinstock criterion for left wheel of leading wheelset in front bogie,
"2" - the sum of absolute values Y/Q for two wheels received from Adams

The same situation can be observed in Fig.18 for left wheels of leading wheelsets in front (L1), 10th (L10) and rear (L20) bogies in comparison with two wheels of common axes.

According to the UIC regulations the value of Y/Q cannot exceed 1.2 for single wheel and the sum of Y/Q for the wheelset must be less than 1.5 for 0.05 second.

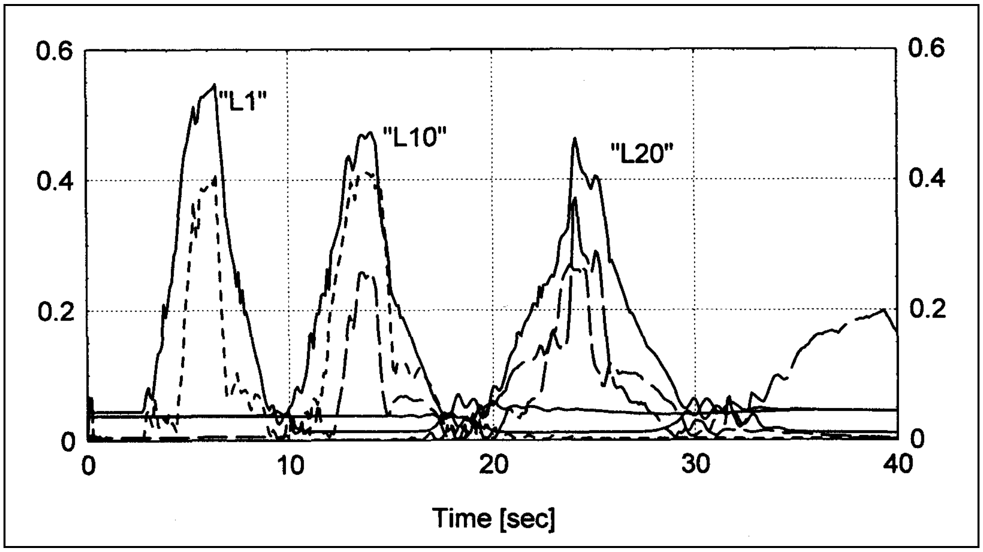


Fig.18. Comparison of absolute values Y/Q for three selected wheelset with two wheels of common axes

6. CONCLUSION

For today, the dynamic behaviour of bimodal train longer than three wagons, running on the curved track has not been investigated.

Results obtained from simulations in ADAMS/RAIL package provide with reliable information concerning safety of long bimodal train (20 coupled car bodies). These results are very important for potential users (rail enterprise) in the close future, because transport of goods in bimodal train belongs to the "JiT" system of transportation - very profitable from economical point of view.

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