BAJER, Czesław and BOGACZ, Roman
Institute of Fundamental Technological Research, Polish Academy of Sciences,
Świętokrzyska 21, 00-049 Warsaw, Poland

DYNAMICS OF Y-TYPE TRACK

Nowadays technological requirements for transportation system increases rapidly. Load carrying capacity of trains, higher speed and environment protected against the noise force rapid development of transportation systems. Considerable progress recently has been made in the field. Both tracks and vehicles have been significantly improved. Ballastless uniform tracks without sleepers or tracks with special sleepers, called Y-type sleepers track are examples of proposed solutions.

The classic and reinforced railway track is composed of two infinite rails separated from the sleepers by visco-elastic pads. There are numerous simplifications in railway track modelling. The rails are modelled as infinite Timoshenko beams, sleepers by lumped masses or elastic bodies and ballast as visco-elastic foundation. The fundamental qualitative difference between the track with classic or Y sleepers is related to local longitudinal symmetric or antymetric features of railway track. The sleeper spacing influences the periodicity of elastic foundation coefficient, mass density (rotational inertia) and shear effective rigidity. The track with classical concrete sleepers is influenced much more by rotational inertia and shear deflections than the track with Y sleepers. The increase of elastic wave velocity in track with Y sleepers and more uniform load distribution will be proved by the analysis and simulations.

We present the dynamic analysis of Y-type track under moving smooth or oscillatory load. The Y-type track is compared with the classical one. The amplitude growth under the moving load and in certain distance in front of the contact points is the main quantity investigated in the paper.

In a classical track sleepers are placed in a distance of 60 cm, leaving the rail between them unsupported. The distance between wheelsets is equal to the multiplication of it, usually 3 m. It results in lower rotatory motion of the vehicle. However, the vertical motion of the vehicle is significant, since all the wheels are affected by the same alteration of the stiffness of rails.

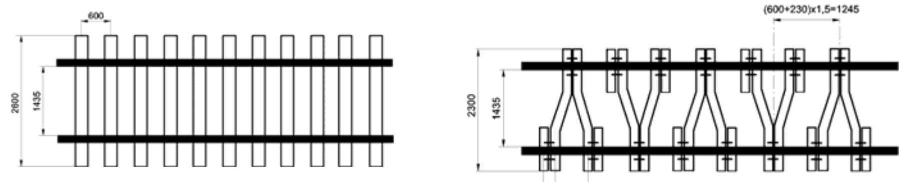

Fig. 1. Classical type of the track (left) and “Y” type (right).

“Y” sleepers are made of steel. The principal idea is to increase the transversal stiffness and to enlarge the inertia of the track by incorporating the ballast into the C-shaped sleepers. Experimental parts of the track exhibits lower noise level. Numerical simulations show reduced vertical amplitudes. The Y-type track is designed for moderate speed.

The conventional and reinforced railway track is composed of two infinite rails mounted to the sleepers by means of elastic pads. There are various assumptions leading to the different simplification in railway track modelling. The two-dimensional periodic model of track consists of two parallel infinite Timoshenko beams (rails) coupled by means of visco-elastic foundation (or equally spaced sleepers). The qualitative difference in track modelling with classic or *Y sleepers* is connected with local longitudinal symmetric or antymetric features of railway track. The dynamical analysis of above tracks models as periodic structures can be based on Floquet’s theorem. The Timoshenko beam model placed on an elastic or visco-elastic foundation can also be used to describe the vertical or lateral track motion. In such a case sleeper spacing influences the periodicity of elastic foundation coefficient, mass density (rotational inertia) and shear effective rigidity. The track with classic concrete sleepers is influenced stronger by rotational inertia and shear deflections than the track with *Y sleepers*. The increase of elastic wave velocity in track with *Y sleepers* and more uniform load distribution will be proved in analysis and simulations.

Let us consider the Timoshenko beam motion described by the following set of partial differential equations:

$$\begin{aligned} &\frac{\partial}{\partial x}\left(K\left(\frac{\partial w}{\partial x}-f\right)\right)-mA\frac{\partial^2 w}{\partial t^2}-cw=p(x,t) \\ &EI\frac{\partial^2 f}{\partial x^2}+K\left(\frac{\partial w}{\partial x}-f\right)-mI\frac{\partial^2 f}{\partial t^2}=0 \end{aligned} \tag{1}$$

where: EI – flexural rigidity, K – shear coefficient, G – shear modulus of elasticity, A – cross-sectional area with moment of inertia I, w – displacement, f – angle of the beam rotation, c – coefficient of elastic foundation and m – mass density. The classic track shown in Fig. 1 (left) is defined by following parameters: E = 2.1·10^{11} *N/m*^{2}, I = 3.052·10^{-5}*m*^{4}, m = 60.31 *kg/m*, c = 2.6·10^8 *N/m*, l = 0.6 *m*, b = 6.3·10^4 *Ns/m*, sleeper mass M = 145 *kg*, visco-elastic foundation C = 1.8·10^8 *N/m* and B = 8.2·10^4 *Ns/m*.

The equation of sleeper motion for the case of symmetric (in phase) rails vibration is as follows:

$$M\ddot{q}+B\dot{q}+Cq=2b(\dot{w}-\dot{q})+2c(w-q) \tag{4}$$

In the case of antimetric rails vibration we have the following equation of sleepers motion

$$J\ddot{p}+B_0\dot{p}+C_0 p=bl(\dot{w}-\dot{p})+cl(w-p) \tag{5}$$

Numerical track model was composed of grid and bar finite elements. Both rails and sleepers were modelled as a grid separated by visco-elastic pads assumed as bar elements. The Winkler type foundation was modelled by visco-elastic springs. The total length of the track was 20 m. Both ends were fixed. Significant damping allowed us to reduce the influence of boundary conditions. The vehicle was built as a mass and spring 3-dimensional system combined with frame elements. The distance between wheelsets was equal to 250 cm. We must emphasize that the coupling of displacements in right and left contact points was performed both by wheelsets and the vehicle frame and was stronger than in the case of the coupling between leading and hind wheelsets.

The vehicle and the track represented by systems of algebraic equations were solved independently by a direct method. The coupling was ensured by iterations. We can say that in spite of simplicity of the approach the results obtained were highly satisfactory.

Examples demonstrate the difference between both tracks. In the first case the perfect wheel is rolling along the track. The vehicle was subjected to gravity forces. The initial stage of rolling into the rails was a sufficient excitation of the system. The response of the wheelset/track system depends on the velocity. In higher range we can notice significant influence of sleepers spacing (Fig. 2).

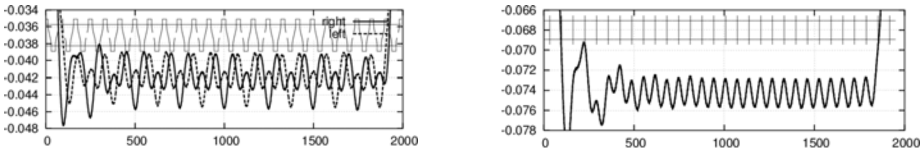

Fig. 2. Vertical displacements of the vehicle/track contact points (50 m/s): Y-type track (left), classical track (right).

In the second test the contact point was additionally subjected to eccentric wheels load. Such a case usually occurs in practice. It can be considered as a periodic load which acts to a wheelset together with the periodicity of the track structure at the speed 40 m/s. The simulation proved significantly lower amplitude level of the track with Y-type sleepers than in the classic case of the track (Fig. 3). Vibration measured in a specified distance in front of the wheelset is important in the case of coupling of interactions of successive vehicles travelling over straight or waved rail. The comparison of both tracks in the whole period of simulation is depicted in Fig. 4. We can notice the waved time-space surface in the case of the classic track. The interesting phenomenon of waves travelling towards the source can be observed. The *Y-type* track exhibits considerably lower level of amplitudes.

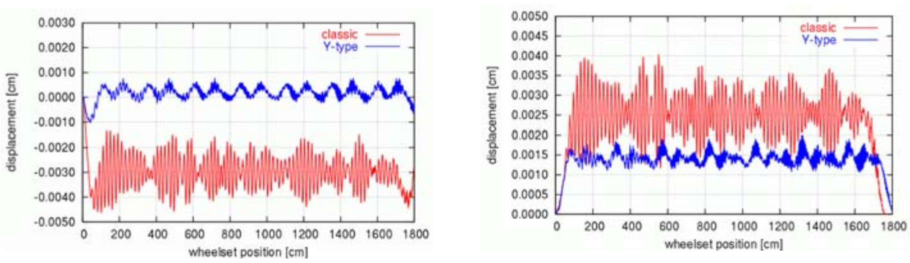

Fig. 3. Vertical displacements registered 120 cm (left) and 180 cm (right) in front of the contact points of the buggy for classic and *Y-type* track at the speed 40 m/s.

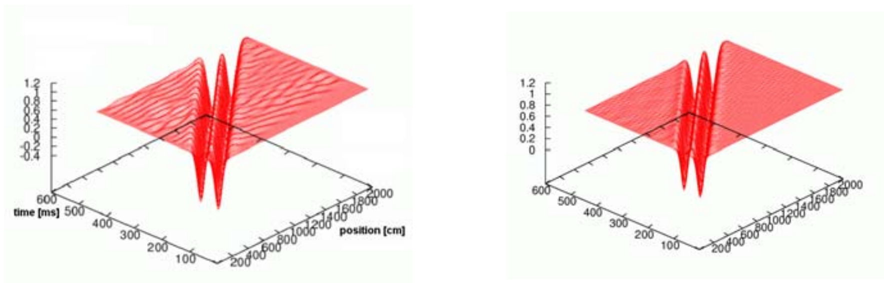

Fig. 4. Vertical displacements of a classic track (left) and *Y type* track (right) in time-space domain subjected by buggy moving with the speed 40 m/s.

Analytical investigations gives the qualitative relations between the track vibrations, especially bending and shear waves, and the speed of the travelling inertial coupled load. Quantitative analysis in practice can be performed numerically. The important question is the modelling of the wheel/rail contact. The analysis with the wheel assumed as a continuous 2 or 3-dimensional disk discretized by finite elements is relatively simple. In the case of vehicle made as a spring-mass system we can not say exactly what amount of the wheel mass should attache the rail in vertical motion. However, numerical analysis proved analytical calculations.

Advantages of Y-type sleepers are significant for practical use. They are characteristic of lower amplitude level and in the same way lower acoustic emission. The wear (for example corrugations) should decrease since the contact force does not oscillate as strongly as in the case of the classic track.

References

1. C. Bajer, The space-time approach to rail/wheel contact and corrugations problem. *Comp. Ass. Mech. Eng. Sci.*, **5**, 267-283, 1998
2. R. Bogacz, Z. Kowalska, Computer simulation of the interaction between a wheel and a corrugated rail, Eur. J. Mech. A/Solids, **20**, 673-684, 2001
3. R. Bogacz, C. Bajer, On modelling of contact problems in railway engineering. *In:* Recent Advances in Applied Mechanics, J.T. Katsikadelis, D.E. Beskos and E.E. Gdoutos, *Eds.*, Nat. Techn. Univ. of Athens, Greece, 77-86, 2002
4. R. Bogacz, T. Krzyżyński and K. Popp. Application of Floquet's theorem to high-speed train/track dynamics. In Advance automotive technologies, ASME Congress, 55-61, 1995.
5. R. Bogacz, S. Dżuła. Dynamics and stability of a Wheelset/Track Interaction Modelled as Nonlinear Continuous System. Machine Dynamics Problems, **20**, 23-24, 1998
6. R. Bogacz, M. Kocjan, W. Kurnik. Dynamics of wheel-tyre subjected to moving oscillating force, Machine Dynamics Problems, 2002