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EFFECT OF TRACK BENDING WAVES ON GENERATING GROUND VIBRATIONS BY HIGH-SPEED TRAINS

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1. INTRODUCTION

In today's World, the railways become one of the most advanced and fast developing branches of transportation [1]. The reasons are relatively low air pollution per passenger, compared to road vehicles, and very high speeds achievable at the most advanced modern trains, e.g., French TGV-trains for which maximum speed of more than 515 km/h was recorded in May 1990. Unfortunately, the increased speeds of modern trains are likely to increase levels of associated noise and vibration that are significant even for conventional railways [2,3].

Although a number of experimental and theoretical investigations of generated ground vibrations have been carried out for conventional passenger and heavy-freight trains, the only theoretical research associated with high-speed trains has been undertaken by the present author just recently [4]. It has been shown that high-speed trains are generally accompanied by higher levels of generated ground vibrations. Especially large increase in vibration level (more than 70 dB, as compared to conventional trains) may occur if train speeds v exceed the velocity of Rayleigh surface waves in the ground c_R (we suggest to call such trains *"trans-Rayleigh trains"*) [4].

In the present paper, we examine the effect of dispersive bending waves propagating in the system track/ground on the shapes of track deflection curves and eventually on generating ground vibrations. It is shown that for high-speed trains the influence of critical track-wave velocities may become essential, resulting in noticeable modification of generated ground vibration spectra.

2. WHEEL-IMPACT FORCES APPLIED TO THE GROUND

There are several mechanisms of generating ground vibrations which may contribute to the total ground vibration level in different frequency bands. Among these mechanisms one can mention the wheel-axle pressure onto the track, the effects of joints in unwelded rails, the unevenness of wheels or rails (all these mechanisms cause vibrations at trainspeed-dependent frequencies), and the dynamically induced forces of carriage- and wheel-axle bending vibrations excited mainly by unevenness of wheels and rails (these occur at their natural frequencies). The most common generation mechanism is a pressure of wheel axles onto the track. It always persists, whereas all other mechanisms may be eliminated (at least in theory) if rails and wheels are ideally even and no carriage or wheel-axle bending vibrations occur. In this paper we consider contribution of the wheel-axle pressure mechanism only.

The form of the track deflection curve determines ground vibration spectra generated by each sleeper. In turn, these spectra strongly affect the resulting ground vibration spectrum generated by a passing train. We treat a track (i.e., two parallel rails with periodically fastened sleepers) as an Euler -Bernoulli elastic beam of uniform weight $p = m_0 g$ lying on an elastic foundation.

To take into account the effects of track bending waves, one should use the dynamic equation

$$EI\, \partial^4 w/\partial x^4 + m_0 \partial^2 w/\partial t^2 + \alpha w = T\,\delta(x-vt)\,. \qquad (1)$$

Here w is beam deflection magnitude, E and I are Young's modulus and the cross-sectional momentum of the beam, α is the proportionality coefficient of the elastic foundation, x is the distance along the beam, T is a vertical point force modelling the wheel impact, and v is a train speed. The solution of (1) has the form (see, e.g., [5])

$$w = (T/8EI\beta^3\delta)\exp(-\beta\delta|x|)[\cos(\beta\eta x) + (\delta/\eta)\sin(\beta\eta|x|)]. \qquad (2)$$

Here $\beta = (\alpha/4EI)^{1/4}$, $\delta = (1 - v^2/c^2_{min})^{1/2}$, and $\eta = (1 + v^2/c^2_{min})^{1/2}$, where $c_{min} = (4\alpha EI/m_0^2)^{1/4}$ is a minimal phase velocity of freely propagating track bending waves. For typical track and ground parameters $c_{min} = 326\ m/s\ (1174\ km/h)$.

It is seen from (2) that if the train speed v approaches the minimal phase velocity of free track waves c_{min}, then $\delta \rightarrow 0$ and the amplitude w in (2) increases. Normally, the values of c_{min} are essentially larger than even the highest train speed ($v = 515\ km/h$). However, for soft sandy or marshy soils in the absence of ballast the values of c_{min} may be much lower. Note that in all cases when the influence of dynamic effects is essential, the track deflection distance, determined as $x_0 = \pi/\beta\delta$, is increased as compared to quasi-static case ($x_0 = \pi/\beta$) [4]. This results in larger numbers of sleepers N_{eff} involved in a deflection area and, hence, in smaller values of the impact forces P applied from each sleeper to the ground.

The forms of a track deflection curve $w(x)$ calculated according to equation (2) for $v < c_{min}$ are shown in Fig.1 for the axle load $T = 100\ kN$ and for the values of train speed v equal to 0, 69, 138, 300 and 320 m/s (curves w1-w5 respectively). One can see that the curves corresponding to the first three values of train speed (i.e., up to 500 km/h) are almost indistinguishable. Only for train speeds approaching the minimal (critical) track wave velocity $c_{min} = 326\ m/s$ a significant difference occurs. The corresponding forces P applied from each sleeper to the ground and calculated according to the approach developed in [3,4] are shown in Fig. 2 as functions of vt for the same parameters as in Fig.1 (curves P1-P5).

3. SPECTRA OF GENERATED GROUND VIBRATIONS

The expression (2) has been used in calculations of ground vibrations generated by high-speed trains. In doing that we followed the methods developed in [3,4].

Fig.3 illustrates the ground vibration spectra (in dB, relative to the reference level 10^{-9} m/s) generated at the distance $y_0 = 30\ m$ by French TGV or Eurostar trains consisting of $N=5$ equal carriages for both sub-Rayleigh and trans-Rayleigh train speeds: respectively $v = 50\ km/h$ (curve Vz1) and $v = 500\ km/h$ (curve Vz2). The Rayleigh wave velocity in the ground was $c_R=125\ m/s$ $(450\ km/h)$, the critical track wave velocity had a value $c_{min} = 326\ m/s$ $(1173.6\ km/h)$, and the soil attenuation coefficient was $\gamma = 0.05$. Other parameters used in calculations were $T = 100\ kN$, and $\beta = 1.28\ m^{-1}$. One can see that the average ground vibration level from a train moving at trans-Rayleigh speed 500 km/h (138.8 m/s) is approximately 70 dB higher than from a train travelling at speed 50 km/h (13.8 m/s). Effect of track bending waves is small in this case because of the significant difference between v and c_{min}.

Fig.4 illustrates the effect of reducing the critical track wave velocity c_{min}, e.g., by making use of softer or thinner ballasts on marshy soils, on generating ground vibration spectra by TGV trains comprising 5 equal carriages and travelling at speed of 500 km/h. Calculations were carried out for $c_{min} = 326\ m/s$ (curve Vz1) and $c_{min} = 140\ m/s$ (curve Vz2); other parameters were the same as in Fig.3. One can see that a lower critical track wave velocity corresponds to lower values of generated ground vibrations. Thus, artificial reduction of the critical track wave velocity may be used in practice to reduce generated ground vibrations.

4. CONCLUSIONS

Increase in speeds of high-speed trains is generally accompanied by increased levels of generated ground vibrations. Especially large increase in ground vibration amplitudes occurs for trans-Rayleigh trains, i.e., for trains travelling at speeds larger than Rayleigh wave velocity in the ground. Calculations performed for French TGV or Eurostar trains show that the averaged increase about 70 dB takes place as compared with conventional trains.

Effect of track bending waves may cause noticeable reduction in amplitudes of ground vibrations generated by trans-Rayleigh trains if the train speeds approach the minimal phase velocity of track waves.

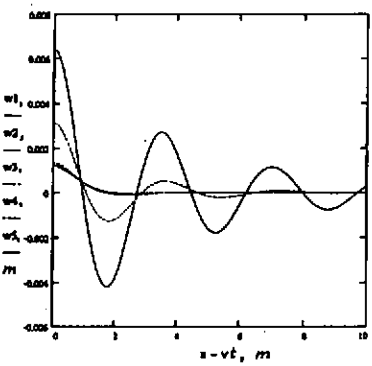

Fig. 1. Calculated track deflection curves taking into account effect of bending waves

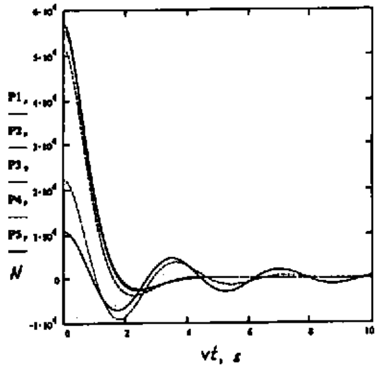

Fig. 2. Impact forces applied from each sleeper to the ground

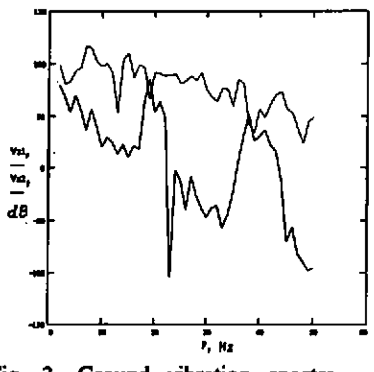

Fig. 3. Ground vibration spectra generated by French TGV or Eurostar trains for sub-Rayleigh and trans-Rayleigh train speeds

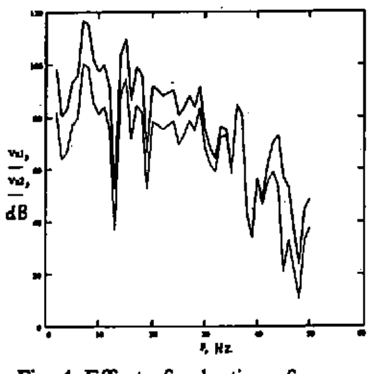

Fig. 4. Effect of reduction of c_{min} on ground vibration spectra generated by French TGV or Eurostar trains

REFERENCES

1. D. Banister and P. Hall, Built Environment, 19, 157 (1994).
2. P.J. Remington, L.G. Kurzweil and D.A. Towers, D.A., Transportation noise. Reference book, Ed. by Paul Nelson (Butterworths, London e.a., 1987).
3. V.V. Krylov and C.C. Ferguson, Applied Acoustics, 42, 199 (1994).
4. V.V. Krylov, Applied Acoustics, 44, 149 (1995).
5. A.I. Belzer, Acoustics of Solids (Springer-Verlag, Berlin, Heidelberg, 1988).