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Modeling the dynamic behavior of the upper structure of the railway track

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Abstract

The present work is devoted to modeling the behavior of railway track under dynamic load of wheel pair in view of elastic, viscoelastic and elastic-plastic properties of the area of interaction between two solids and elastic anisotropic properties of the subgrade, which differ in three main areas: along the rails along the sleepers and vertically downwards. The wave equation railway tracks suggest that the deformation and the permanent way and the mound itself is the field of interaction of bodies takes place in view of the spread of a finite speed of the wave surfaces. The solution methods used methods of asymptotic expansions in the time and space coordinate, the method of matching the expansions obtained for short times in the contact zone and outside it.

Keywords: dynamic interaction, the condition of compatibility, railway embankment, engineering-geological factors, dynamic sag.

1. Introduction

to explore in detail the process of dynamic loading of the track structure with subsequent establishment of dependencies for buckling and stresses it is necessary to simulate the dependencies of the force of interaction on different types of deformation (including bearing deformation) [1-12]. The main approaches that allow the detailed modeling of the interaction process between two rigid bodies differ from one another in the force acting in the contact area [1-5] and the nature of motion of the track (rail) points outside of the interaction region [6-12].

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After the beginning of the interaction of the wheel set, which is represented by a solid body and the construction of the top ways [13-16], the contact area with the radius of r_0 is formed in this construction and both the quasi-longitudinal and quasi-transverse waves [17-19], which fronts represent surfaces of strong discontinuity, start to propagate from its surface [20-22].

2. Governing equation for wave problem

The embankment of the railway is modeled by an elastic orthotropic two-dimensional Uflyand-Mindlin element that exhibits a cylindrical anisotropy. In the polar coordinate system, the dynamic behavior of this element is described using equations which take into account the rotary inertia of the cross sections, deformation of the transverse shear and axial symmetry of the problem [4]:

$$\frac{\partial^2\varphi}{\partial r^2}+\frac{1}{r}\frac{\partial\varphi}{\partial r}+\frac{1}{r^2}\frac{\partial^2\varphi}{\partial\theta^2}-\frac{1}{r^2}\frac{c_2}{c_1}\varphi+\frac{c_2\sigma_r+c_3}{c_1 r}\frac{\partial^2\psi}{\partial r\partial\theta}-\frac{c_2+c_3}{c_1 r^2}\frac{\partial\varphi}{\partial\theta}+\frac{12c_4}{c_1}\left(\frac{\partial w}{\partial r}-\varphi\right)=-\frac{\partial^2\varphi}{\partial\tau^2},$$

$$\frac{c_4}{c_1}\left(\frac{\partial^2 w}{\partial r^2}-\frac{\partial\varphi}{\partial r}\right)+\frac{c_4}{c_1}\left(\frac{\partial w}{r\partial r}-\frac{\varphi}{r}\right)+\frac{c_4}{c_1}\left(\frac{\partial^2 w}{r^2\partial\theta^2}-\frac{\partial\psi}{r\partial\theta}\right)=\frac{\partial^2 w}{\partial\tau^2}+q_1,$$

$$\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)+\frac{c_3}{c_1 r^2}\frac{\partial^2 u}{\partial\theta^2}-\frac{c_2}{c_1}\frac{u}{r^2}+\frac{c_2\sigma_r+c_3}{c_1 r}\frac{\partial^2 v}{\partial r\partial\theta}-\frac{c_2+c_3}{c_1 r^2}\frac{\partial v}{\partial\theta}=\frac{\partial^2 u}{\partial\tau^2}, \quad (1)$$

$$\frac{c_2}{c_1 r^2}\frac{\partial^2 v}{\partial\theta^2}+\frac{c_3}{c_1}\left(\frac{\partial^2 v}{\partial r^2}+\frac{1}{r}\frac{\partial v}{\partial r}-\frac{v}{r^2}\right)+\frac{\sigma_\theta+c_3}{c_1 r}\frac{\partial^2 u}{\partial r\partial\theta}+\frac{c_2+c_3}{c_1 r^2}\frac{\partial u}{\partial\theta}=\frac{\partial^2 v}{\partial\tau^2},$$

$$\frac{c_3}{c_1}\left(\frac{\partial^2\psi}{\partial r^2}+\frac{1}{r}\frac{\partial\psi}{\partial r}-\frac{\psi}{r^2}\right)+\frac{c_2}{c_1 r^2}\frac{\partial^2\psi}{\partial\theta^2}+\frac{\sigma_\theta+c_3}{c_1 r}\frac{\partial^2\varphi}{\partial r\partial\theta}+\frac{c_2+c_3}{c_1 r^2}\frac{\partial\varphi}{\partial\theta}+\frac{12c_5}{c_1}\left(\frac{1}{r}\frac{\partial w}{\partial\theta}-\psi\right)=-\frac{\partial^2\psi}{\partial\tau^2},$$

where $\tau=\frac{t\sqrt{c_1}}{h}, w=\frac{w}{h}, u=\frac{u}{h}, v=\frac{v}{h}, r=\frac{r}{h}, c_1=\frac{E_r}{(1-\sigma_r\sigma_\theta)\rho}, \quad c_2=\frac{E_\theta}{(1-\sigma_r\sigma_\theta)\rho}, \quad c_3=\frac{G_{r\theta}}{\rho}, \quad c_4=\frac{KG_{rz}}{\rho},$ $c_5=\frac{KG_{\theta z}}{\rho}, \; q_1=\frac{qh}{\rho c_1}, \; D_r=\frac{h^3}{12}B_r, \; D_\theta=\frac{h^3}{12}B_\theta, \; D_k=\frac{h^3}{12}B_k, \; C_r=hB_r, \; C_\theta=hB_\theta, C_k=hB_k, \; D_{r\theta}=D_r\sigma_\theta+2D_k,$ $B_r=\frac{E_r}{1-\sigma_r\sigma_\theta}, \; B_\theta=\frac{E_\theta}{1-\sigma_r\sigma_\theta}, \; B_k=G_{r\theta}, \; E_r\sigma_r=E_\theta\sigma_\theta, \; K=5/6$, D_r, D_θ and C_r, C_θ - the bending regidity and and tension-compresiion rigidity for r and θ directions, respectively; D_k – the torsional regidity; C_k – the shear stiffness; E_r, E_θ and σ_r, σ_θ - the coefficients of elastisity and Poisson's ratios for r and θ directions, respectively; G_{rz}, $G_{\theta z}$ – the shear modules for rz and θz planes, respectively; $w(r,\theta)$ – the normal displacement of the median plane, $u(r,\theta)$ and $v(r,\theta)$ – the tangential displacements of the medial surface with respect to r and θ coordinates; $\varphi(r,\theta)$ and $\psi(r,\theta)$ – the rotation angles of the normals in r and θ directions r,θ (fig.1), ρ - density, q – load, R_1 – radius of spherical impactor, h – thickness of the plate.

To determine the unknown displacements in Eq. (1) the following series expansion can be used [2,4,5,6]:

$$Z(s,t)=\sum_{k=o}^{\infty}\frac{1}{k!}\left[Z_{,(k)}\right]_{t=s/G}\left(t-\frac{s}{G}\right)^k H\left(t-\frac{s}{G}\right), \quad (2)$$

where Z – the required function, $Z_{,(k)}={}^kZ/t^k$, , the upper indices «+» and «-» of the derivative $Z_{,(k)}$ indicate that the value is found in front of and behind the wave surface, respectively, G – the normal velocity of the wave, $H(t\text{-}s/G)$ – the Heaviside step function, s – length of a curve, measured along the ray, t – time.

The proposed method is based on the applying the geometric and kinematic conditions of compatibility, suggested in reference [1] and developed for physical components in the paper [2] as follows: