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Brief note

DYNAMICS OF WELDED RAILS GAP AND HARDNESS OF RAIL BASE

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The problem of gap estimation for a break of a continuous welded rail is studied. The track is represented as a semi-infinite rod on elastic-based damping. Static and dynamic solutions are obtained. It is shown that during the rail break, the dynamic factor does not exceed 1.5. We derive equations for thermal deformation of the welded rail of jointless track on an elastic foundation in the presence of the insert into the base with another characteristic stiffness. It is shown that the presence of the insertion of up to *20*% of the length of the rail, with both large and small stiffness, has a little effect on the stress-strain state (SSS) of the track. The presence of a rigid insert may increase the clearance of an accidental break of the rail, which has a negative effect on traffic safety.

Key words: continuous welded rail, stress-strain state.

1. Introduction

Continuous welded rail is now the main type of track for railways. For high-speed lines this way is considered to be the only possible (Takagi [1]). Its successful use is related to solving two problems: rail rupture under low temperature and rail stability under high temperature. Operating experience of continuous welded rail shows that the rupture of the rail track on the macadam ballast in compliance with all requirements of stowage and securing, clearances occurs up to 6-8 cm (Kondratyev [2]). These gaps are acceptable and do not cause derailment. There are estimations (Novakovic *et al*. [3]) of static clearance, which remains after fracture and after the passage of a train. Rupture of the rail occurs usually under the train and at break moment the dynamic displacement of the rail ends exceeds the static ones (Novakovic *et al*. [3]). Until now, there is no solution of the problem of dynamic vibrations of the rail at break. Additional limitation on using of continuous welded is related to the influence of stiffness of the rail base on the stress-strain state of welded rails (Kondratyev [2]). At high rail base stiffness and rigid connection of the rail and the base, there are significant stresses that can cause it to break (in winter) or can cause bulging (in summer). At low stringency of connection and opportunities to slip, stresses in the rail reduce. On other hand, in this case, there is a risk of a large gap at random break of welded rail that violates traffic safety (Andreev [4]).

2. Models

2.1. Dynamic displacement of the rail

To estimate the dynamic displacement of the rail we consider a semi-infinite rod lying on a solid elastic-based damping. (Fig.1).

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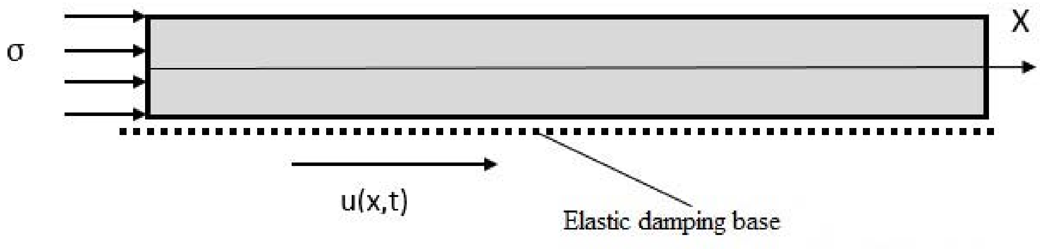

Fig.1. The computational model of the rail on the basis of elastic-damping (ballast).

Stress σ which is equal to the break stress for the rail is instantly applied to the end of the rod. For thermostrengthened welded rails the break stress is *400* MPa. The problem under consideration has not yet been solved. In practice, one believes that the disclosure of the dynamic gap is 1.5-2 times greater than the static. An equation of oscillations of the system is given by Zhanga Guo-Dong and Guo Bao-Zhu [5]; Beshliu [6]

$$\rho F u_{tt} = EFu_{xx} - Ku - Bu_t \tag{2.1}$$

where K is the linear stiffness, B- is the damping per unit length $B = \frac{\gamma K}{\omega}$, E - is the modulus of elasticity of the rail, ρ- is the density of steel, F - is the cross-sectional area of the rail, γ - is the coefficient of inelastic resistance, ω - is the frequency oscillation, u - is the offset, u_t - is the speed, u_{tt} - is the acceleration.

Equation (2.1) is considered under zero initial conditions and the following boundary conditions

$$u_x = \frac{\sigma}{E}\eta(t), \qquad u(\infty, t) = 0$$

where σ is the breaking stress for the welded rail, η is the Heaviside function. The solution of Eq.(2.1) for $x = 0$, i.e. the displacement of the rail end is given by the formula

$$u(0,t) = \frac{\sigma_0}{E} c \int_0^t e^{-\nu t} J_0(\alpha t) dt \tag{2.2}$$

where σ_0 is the stress, $c = \sqrt{\frac{E}{\rho}}$ - is the wave propagation velocity in the rail, ρ - is the density of steel, $\nu = \frac{\beta}{2}$, J_0 is the Bessel function, $\alpha = \kappa - \frac{\beta^2}{4}$, β - is the linear viscosity $\beta = \frac{B}{\rho F}$, κ - is the ballast stiffness $\kappa = \sqrt{\frac{K}{F\rho}}$.

To estimate the dynamic factor, consider a static value of the gap. The equation for evaluating the displacement at break rail has the form

$$EFu_{xx} - Ku = 0\,. \tag{2.3}$$

A solution of Eq.(2.3) for $x = 0$ is given by

$$u_{cm}(0) = \frac{\sigma}{\lambda E} \tag{2.4}$$

where $\lambda = -\sqrt{\dfrac{K}{EF}}$.

If we divide the expression (2.4) by (2.2), we obtain the formula for calculating the dynamic coefficient $\mu(t)$

$$\mu(t) = \lambda c \int_0^t e^{-\nu t} J_0(\alpha t) dt$$

Figure 2 shows the dependence of the change of the dynamic coefficient over time for different values of K and B.

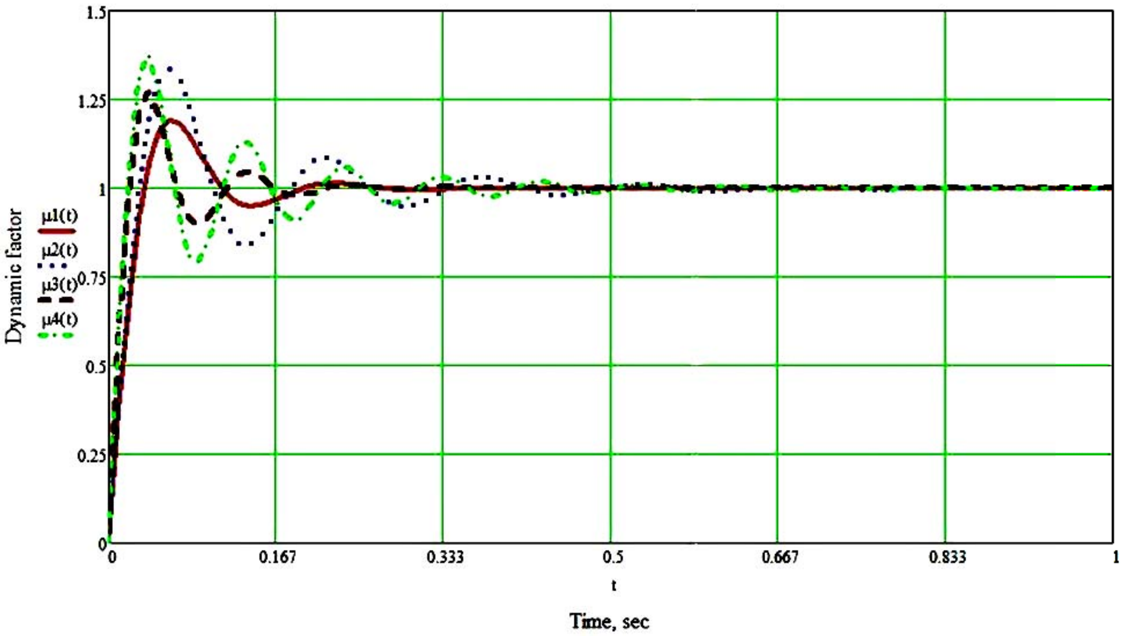

Fig.2. Changes of the dynamic coefficient over time for different values of K and b

$\mu 1$(t): $K_{min}=1000\ kN/m^2$ $b_{max}=25\ c^{-1}$

$\mu 2(t)$: $K_{min}=1000\ kN/m^2$ $b_{min}=10\ c^{-1}$

$\mu 3(t)$: $K_{max}=2500\ kN/m^2$ $b_{max}=25\ c^{-1}$

$\mu 4(t)$: $K_{max}=2500\ kN/m^2$ $b_{min}=10\ c^{-1}$

One can see that in all cases the coefficient of dynamics does not exceed 1.5. The highest value of the coefficient of dynamics is obtained for the frozen old ballast.

2.2. Influence of the base insert

The next challenge is related with the local change of base characteristics. Namely, we consider a welded rail on an elastic foundation in the presence of an insert into the base having another characteristic stiffness (see, e.g., Beshliu [6]; Zaitseva and Uzdin [7]; Zhgutova and Uzdin [8]; Novakovic and Grigorieva [9]; Peregudova and Vinogorov [10]). This may be due to the presence of man-made structures in the body of the mound, freezing ballast, etc. We examine the impact of these factors on the stress-strain state of the welded rail under the change of temperature (see, e.g., (Novakovic [11]).

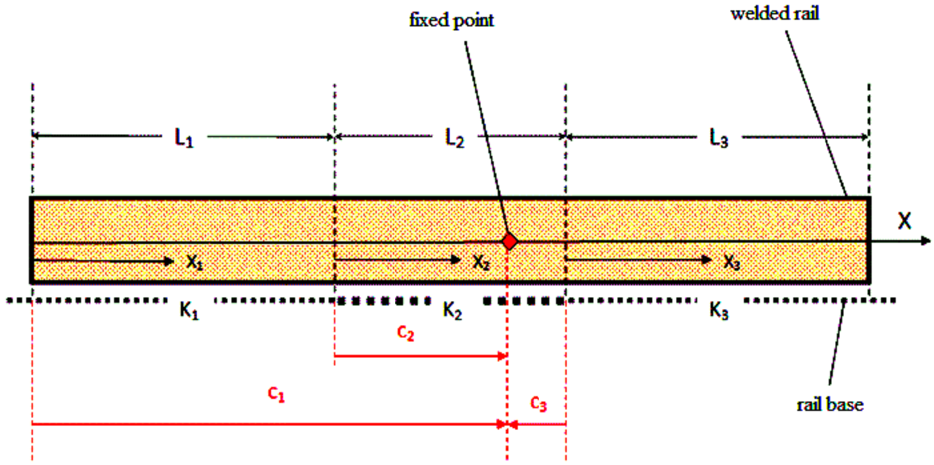

Fig.3. Scheme for the calculation of welded rail.

A scheme for the calculation of the welded rail is shown in Fig.3. The welded rail has a total length L, equal to usually, *850 m*, which is based on the elastic stiffness *K* [3], wherein there is the attaching portion inside the welded rail greater or lesser rigidity. As a result, the welded rail is naturally divided into 3 sections of lengths L_1, L_2 and L_3; $L_1 + L_2 + L_3 = L$.

Equation of SSS for the welded rail is written as (Zhanga Guo-Dong and Guo Bao-Zhu [5])

$$EFu'' - Ku = K\alpha t(x-c) \tag{2.5}$$

where *EF* is the longitudinal rigidity of the rail; *K* - the linear stiffness of the rail base; $\alpha = 1.1 \cdot 10^{-5}$ *m/deg* - is the coefficient of thermal elongation of the rail; *t* - is the heating temperature of the rail; *x* - is the coordinate of the point considered in the adopted coordinate system; *c* - is the coordinate of a fixed point; $K\alpha t(x-c)$ - is the reaction of the rail base when the welded rail is heated.

Let us represent Eq.(2.5) as follows

$$u'' - \kappa^2 u = \kappa^2 \alpha t(x-c) \tag{2.6}$$

where $\kappa^2 = \dfrac{K}{EF}$,

u - shift rail

$$u = -\alpha t x + u_0 .$$

The solution of Eq.(2.6) has the form

$$u = C_{1i}e^{\kappa x} + C_{2i}e^{-\kappa x} - \alpha t(x-c)$$

where C_{1i}, C_{2i} are some constants. The stress of the welded rail has the form

$$\sigma = \left(\left(C_{1i}e^{\kappa x} + C_{2i}e^{-\kappa x}\right)\kappa - \alpha t\right)E$$

Figures 4-6 show the diagrams of the displacements and stresses in the welded rail for different values of the stiffness of ballast and rail when heated to 40^0. Figure 4 illustrates the variation of stresses and displacements in the absence of the insert into the base of the welded rail at each of the sites of stiffness $\kappa_1 = \kappa_2 = \kappa_3 = 0.02$.

Figure 5 illustrates the variation of displacements and stresses in rigid inserts into the base of the welded rail. One can see that there is a region of a sharp drop in stress, and the bias of one of the edges of the rail increases or decreases.

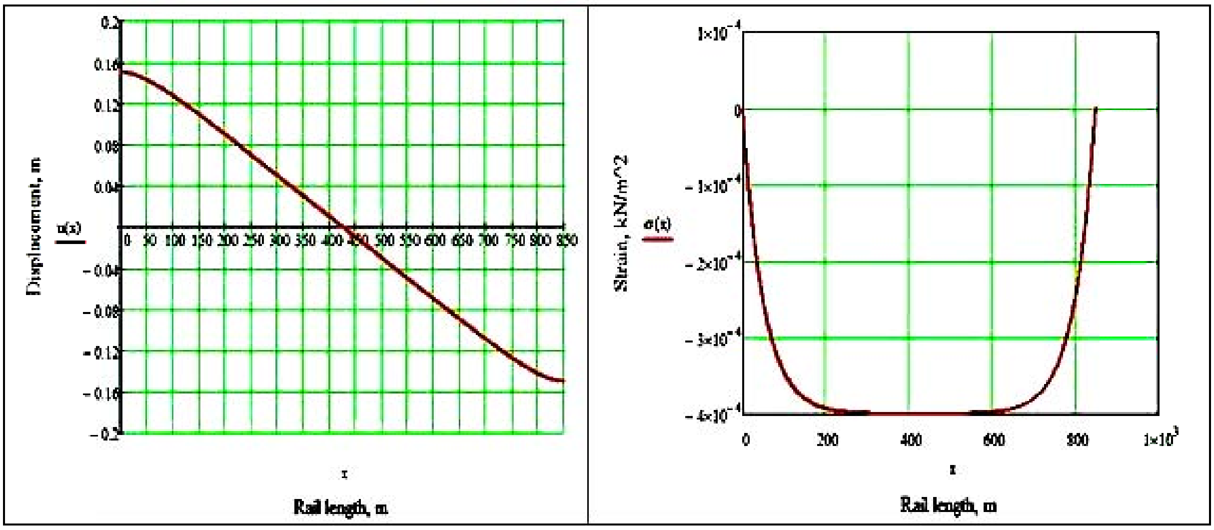

Fig.4. Change of displacements and stresses in the rail along the length of the welded rail with $\kappa_1=\kappa_2=\kappa_3=0.02$ (no insert).

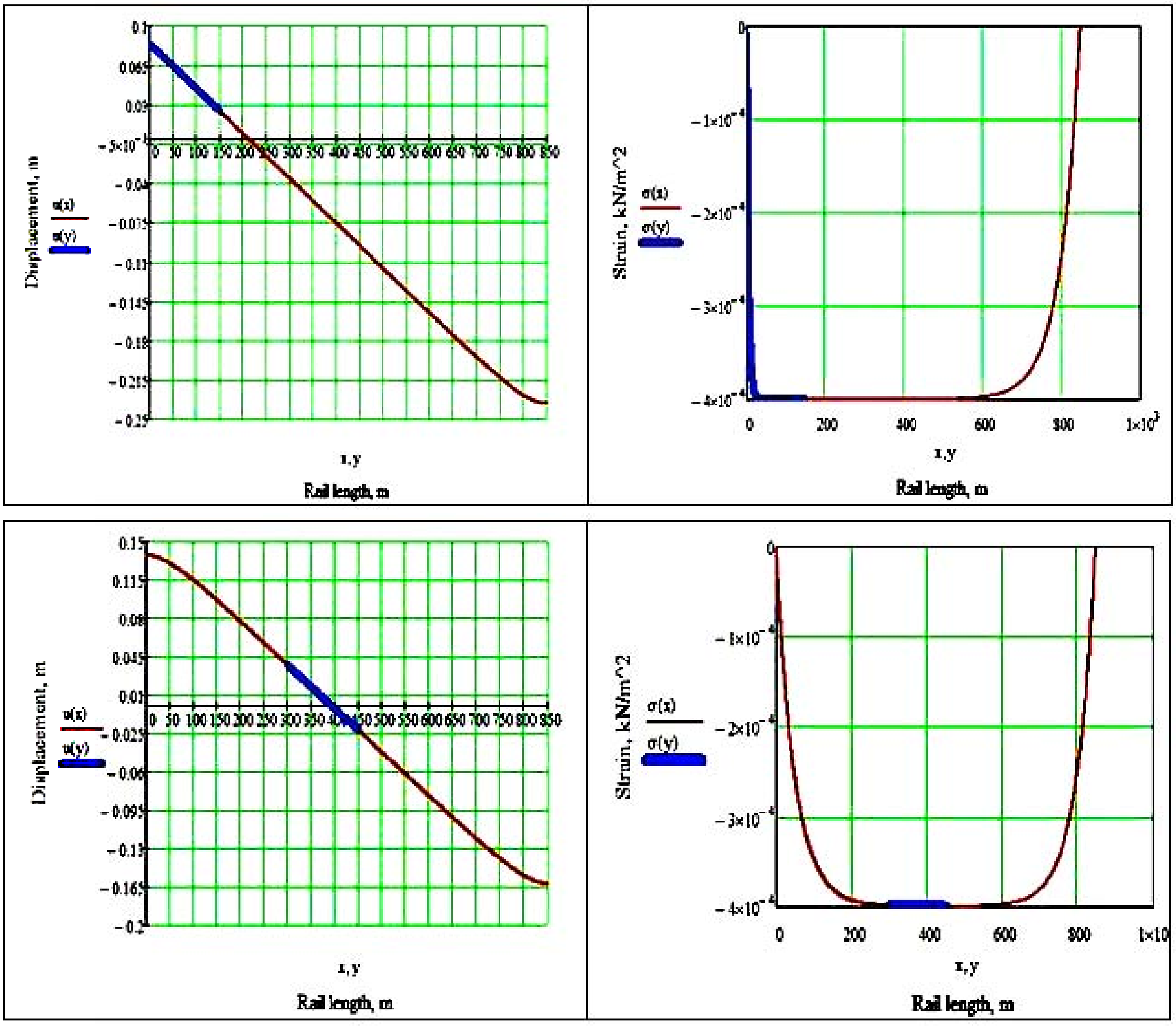

Fig.5. Change in displacements and stresses in the rail along the length of rail lashes with $\kappa_1=\kappa_3=0.02$, $\kappa_2=0.2$.

Figure 6 illustrates the change in the displacement and stress for flexible insert into the base of the welded rail.

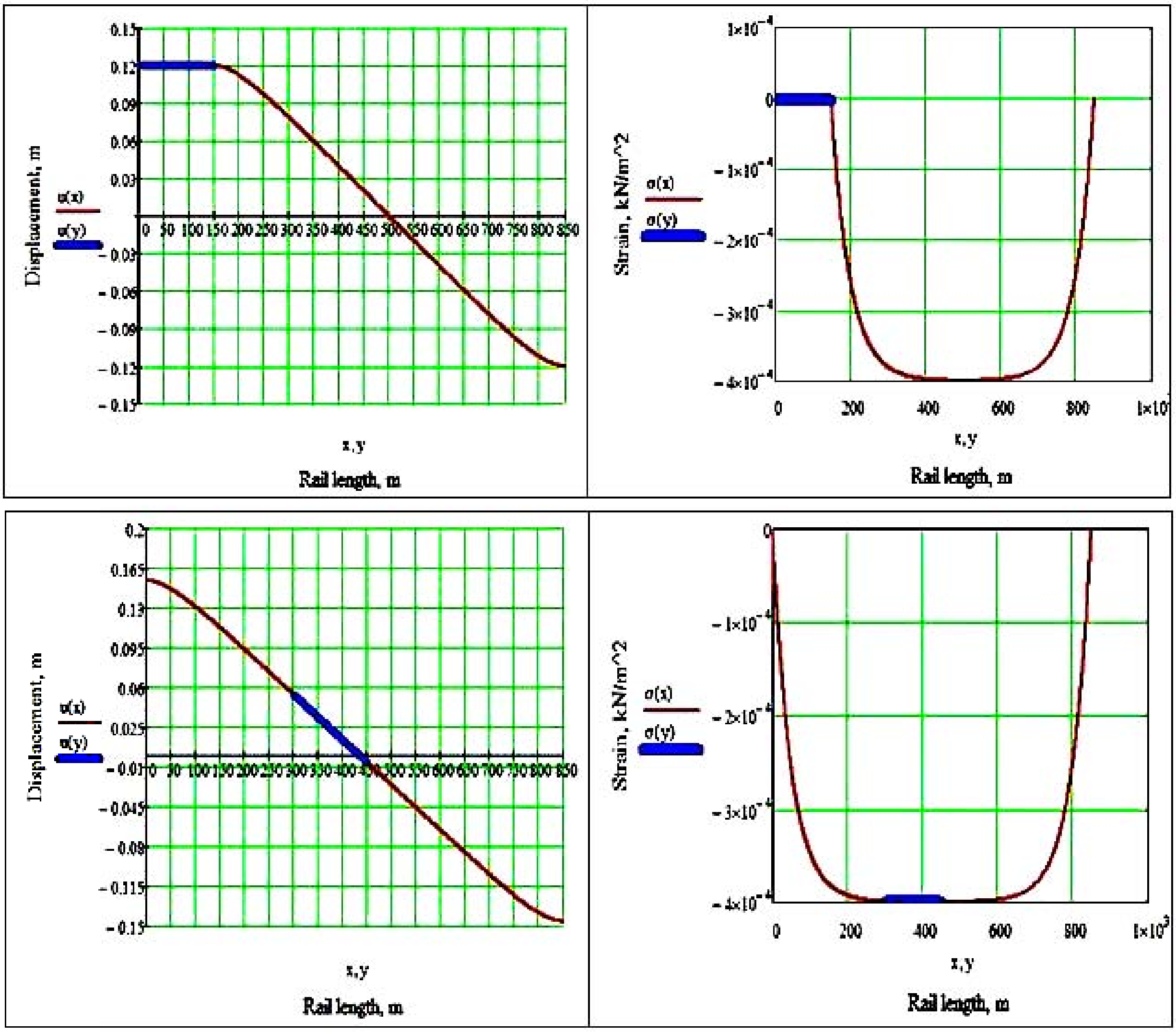

Fig.6. Change in displacements and stresses in the rail along the length of the welded rail with $\kappa_1 = \kappa_3 = 0.02$, $\kappa_2 = 0.0000002$.

3. Conclusion

From the above it follows that:

- Analysis of the solution for the vibration of the edge of the welded rail at the time of rupture allows us to conclude that the possible magnitude of the gap is *10-12 cm* at random kink rail.
- Analysis of SSS of the welded rail on inhomogeneous elastic foundation shows that the presence of a limited area of rail base stiffening change does not lead to a significant change of SSS of the welded rail, but can lead to an increase in the gap at break of the welded rail.

Acknowledgements

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