Experimental study of continuous welded rails deformation under the effect of axial force

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Abstract. On the Russian railways there is a transition from conventional rail to a continuous welded rail track, however during its operation, occasional track disturbances occur due to internal stresses in the rails caused by the temperature and longitudinal stresses generated by passing rolling stock and creepage of the railway. Stresses can be tensile in winter and compressive in summer. They can reach dangerous values leading to rupture of the track at low temperatures and its ejection at high temperatures. To ensure traffic safety, it is necessary to develop a technology for monitoring stresses arising during operation. The authors created and obtained a patent for a device which made it possible to determine the generated stresses. Studies were carried out on welded rail behaviour and the dependence of displacements and stresses on the action of an external force was obtained.

1. Introduction
The author created “a device for determining the longitudinal stiffness of a rail track” (patent for utility model RU 138300 U1) [1]. With this device a longitudinal force \( P \) is applied to the rails, the displacement of the rails \( \delta \) is determined and the stresses generated in the rails are calculated.

2. Methods
We study the option when compressive stresses \( (\sigma_t) \) appeared in rails due to low temperatures. The design scheme is presented in figure 1(a). The longitudinal force \( P \) is generated in the rail by the train, as a result, the distributed resistance force \( q \) acts on the rail from the embankment and the sleeper base (figure 1(b)) [2, 3].

The stresses generated in the rails are as follows:
- temperature stress \( \sigma_t \) (figure 1(c)) [2, 3];
- longitudinal stress on the force \( P \) (figure 1(d)) [4, 5];
- longitudinal stress caused by the distributed resistance force from the action of the upper structure of the track \( q \) (figure 1(e)) [2, 6].

It was accepted that:
- the force \( P \) acts at a distance of \( 2d \);
- the force from the action of the upper structure of the track on the rail has a linear relationship (figure 1(b)):
\[ q_z = q_0 \cdot \frac{z}{d}; \]

- compressive temperature stresses \( \sigma_t \) are evenly distributed in length (figure 1(c));

- longitudinal stresses in the rail from the action of the force \( P \) are distributed according to a linear relationship (figure 1(d)):
  \[ p_z = \frac{P \cdot z}{2 \cdot d \cdot F}; \]

- stress \( \sigma_q \) from the action of the railway track on the rail is determined by the dependence (figure 1(e)):
  \[ \sigma_q = q_0 \cdot \frac{z^2}{d \cdot 2 \cdot F}. \]

The potential energy of deformation caused by the temperature is determined by the dependence:
\[ U_0 = 2 \cdot \int_0^d \sigma_t^2 \cdot P^2 \, dz \cdot 2 \cdot E \cdot F. \] (1)

The potential energy of deformation under the temperature \( \sigma_t \), longitudinal force \( P \), resistance force \( q \):
The increment of potential strain energy:

$$\Delta U = U_1 - U_0.$$  \hspace{1cm} (3)

After the conversion of equations (1), (2), (3) we obtain:

$$\Delta U = \frac{\sigma_1 \cdot q_0 \cdot d^2}{3 \cdot E} + \frac{P^2 \cdot d}{12 \cdot E \cdot F} - \frac{q_0^2 \cdot d^3}{20 \cdot E \cdot F}. \hspace{1cm} (4)$$

The increment of the potential energy of deformation is equal to the sum of the work of external forces:

$$\Delta U = \Delta U_i^c. \hspace{1cm} (5)$$

Experimental studies were conducted on the dependence of the displacement $\delta$ of the point of application of force $P$ on its magnitude (see the graph in figure 2).

We represent the loading curve as a function:

$$P = a \cdot \delta^m. \hspace{1cm} (6)$$

We determine the coefficient $m$ and, substituting $P_1$ and $P_2$, $\delta_1$ and $\delta_2$, we obtain:

$$m = \frac{\ln P_2 - \ln P_1}{\ln \frac{\delta_2}{\delta_1}}. \hspace{1cm} (7)$$

We express the coefficient $a$ as:
\[ a = \frac{P}{\delta^m} \] (8)

3. Results
In this section we calculate rail track parameters.
We find the sum of the work of external forces from formulas (6), (7), (8) and, having transformed, we get:
\[ \sum A^e_i = \int_0^\delta P(\delta) = \int_0^\delta a \cdot \delta^m = \frac{P \cdot \delta}{m+1}. \] (9)

The sum of the forces is expended on the deformation of the rail track and the loss of energy during its movement:
\[ \sum A^e_i = A + A_q. \]

Work spent on elastic deformation is as:
\[ A = \frac{1}{2} \cdot \delta \cdot P, \]
where the displacement \( \delta \) is found according to the graph in figure 2.
Work from energy loss:
\[ A_q = \sum A^e_i - A = \frac{P \cdot \delta}{m+1} - \frac{1}{2} \cdot \delta \cdot P. \] (10)

Elastic deformation is found by Hooke's law:
\[ \delta = \frac{P \cdot d}{E \cdot F}. \]

Then, the length of the railway track \( d \), deforming from the action of the force \( P \):
\[ d = \frac{\delta_{\text{elast}} \cdot E \cdot F}{P}. \] (11)

The work of strain energy loss is caused by the action of the resistance force of the upper structure of the path \( q \):
\[ A_q = A_q = 2 \int_0^d q_z \cdot \delta \cdot \frac{z}{d} dz. \]

By transforming (11), and also expressing the length \( d \) (10), we obtain:
\[ A_q = A_q = 2 \cdot q_0 \cdot \delta \cdot \frac{E \cdot F}{P}. \]

By substituting the work of energy loss (10), we obtain the maximum value of the resistance force from the action of the upper structure of the path \( q_0 \):
\[ q_0 = \frac{P^2 \cdot \left( \frac{\delta}{m+1} - \frac{1}{2} \cdot \delta_{\text{elast}} \right)}{2 \cdot \delta \cdot \delta_{\text{elast}} \cdot E \cdot F}. \]
After the transformation (5), (4) and (9), we obtain:

\[
\frac{\sigma_1 \cdot q_0 \cdot d^2}{3 \cdot E} + \frac{p^2 \cdot d}{12 \cdot E \cdot F} + \frac{q_0^2 \cdot d^3}{20 \cdot E \cdot F} = \frac{P \cdot \delta}{m+1}.
\]

Defining the emerging stresses of the jointless track should be calculated as follows:

\[
\sigma_t = \frac{P \cdot \delta}{m+1} - \frac{p^2 \cdot d}{12 \cdot E \cdot F} - \frac{q_0^2 \cdot d^3}{20 \cdot E \cdot F} \cdot \frac{3 \cdot E}{q_0 \cdot d^2}.
\]

4. Conclusion
Using this method, you can:
- find emerging stresses in a rail in a dangerous place and compare it with permissible ones;
- find the shear resistance of the rail track and determine its technical condition.

Acknowledgments
The work was supported by State task of the Ministry of Science and Higher Education of Russian Federation, projects No. 9.7667.2017/8.9 and No. 9.11221.2018/11.12.

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