The Use of Polymer Flexible Joint Technology in Tramway Tracks Construction

Introduction

It is very important to minimize displacement of tram tracks construction, using in logistic of urban public transport. Tram vehicles have a very little tolerance for geometrical deviations of the surface in both longitudinal and transverse directions. The tram tracks are subjected to relatively high loads coming from tram’s wheels, ground pressure, irregular ground settlement or temperature loads. All these effects generate displacements whose maximum value cannot exceed the limit value [1].

Construction dilatations are an important element of tram tracks made of prefabricated concrete plates [2, 3]. They enable elements’ movement due to temperature expansibility, ensuring water tightness at the same time. One of their most important function is to protect the track from water penetration, especially in winter season. Unfortunately, the destruction of dilatations [4] are often observed in concrete tram surfaces, examples of damage are shown in Fig. 1.

Polymer Flexible Joint (PFJ) technology is an alternative for typical dilatations. Due to its high deformability and hyperelasticity it may be a revolutionary technology for track joints. Besides water tightness, PFJ positively affects the statics of entire construction, due to its ability to carry load in high deformation states [5].

In this work it is numerically analyzed how PFJ influences displacement reduction in typical tram track construction, often used in Poland. It is also shown how two-layer construction variant, which is an original one of the author’s solution, positively influences deformation of the surface.

Fig. 1. Traditional dilatation degradation observed in concrete surfaces

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Analyzed construction’s description

A typical tram track technology is an object of analysis of this work. This constructional solution is often used in Poland, for example in Krakow. Cross-sections are presented in Fig. 2. It was assumed that the concrete slabs are located on linearly elastic support. There were analyzed two variants of support’s elasticity, of 50 MPa (for weak ground) and 100 MPa (for properly prepared track foundation). The surface was loaded with eight surface loads, of a value of 17 kN per surface, representing tram weight. Spacing of the loading forces is shown in Fig. 3. Other load cases were intentionally omitted. Dead loads were omitted in order to show the influence of track’s construction on displacement reduction during tram passes.

In order to minimize dislocations in constructions located on weak foundation, an original construction proposition of two-layer structure has been developed. In this solution, there is located an anti-vibration mat between two concrete layers. It is analyzed how this construction variant influences slabs’ deflections. The solution’s dimensions have been presented in Fig. 4.

In this work there were developed eight constructional variants of the tram track. There was assumed the polymer layer’s thickness of 2 cm in all variants analyzing PFJ influence. All the results have been compared. Table 1 represents description of all eight numerical model’s variants.
Fig. 4. Construction longitudinal (at the top) and cross-section (at the bottom) in two-layer variants

Table 1. Numerical model variants’ description

<table>
<thead>
<tr>
<th>Variant number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>1</td>
<td>1</td>
<td>2</td>
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</tr>
<tr>
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<td>without PFJ</td>
<td>without PFJ</td>
<td>without PFJ</td>
<td>without PFJ</td>
<td>without PFJ</td>
<td>without PFJ</td>
<td>PFJ</td>
</tr>
<tr>
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<td>50 MPa</td>
<td>50 MPa</td>
<td>50 MPa</td>
<td>100 MPa</td>
<td>100 MPa</td>
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</table>

Research methodology

In order to show the influence of different track’s variant application there has been performed a series of numerical simulations in Abaqus 6.12, basing on Finite Element Method [6]. Three dimensional models use C3D8R (for concrete) and C3D8H (for polymer) type elements. The FEM mesh has been concentrated in joint zones. Visualization of one- and two-layer numerical models is shown in Fig. 5 and 6 respectively. Concrete and anti-vibration mat has been modeled as linearly elastic material of following parameters: E=35 GPa, $\nu=0.18$ (for concrete) and E=0.15 GPa, $\nu=0.18$ (for the mat). Polymer has been modeled as Mooney-Rivlin hyperelastic material, according to following formula:

$$U = C_{10}(I_1 - 3) + C_{01}(I_2 - 3) + \frac{1}{D_1}(f^e - 1)^2$$  \hspace{1cm} (1)

where $U$ is the strain energy per unit of reference volume; $C_{10}$, $C_{01}$ and $D_1$ are temperature-dependent material parameters; $I_1$ and $I_2$ are the first and second deviatoric strain invariants.
A nonlinear geometrical numerical analysis has been performed due to big deformations of PFJ. Elastic support has been modeled using predefined Abaqus function “elastic foundation”. This boundary condition introduces a linear dependency of reaction in a particular node from displacement, and can be interpreted from mechanical point of view as Winkler’s support [6].

Results

Influence of PFJ application

There are presented maps of displacements for eight construction variants in Fig. 7 and Fig. 8, according to Tab. 1. Presented values concern bottom surface of the slabs and show displacement caused by the tram load. All the maps are presented in the same scale.

Result analysis leads to conclusion that PFJ application significantly reduces construction’s deformation. PFJ usage leads to more even displacement distribution, due to mechanical connection between slabs increasing total ground area carrying load. It is also connected with better stress distribution, which is shown on stress maps presented in Fig. 9.
Fig. 7. Displacement maps of the lower surface for construction variants with support stiffness of 50 MPa
Fig. 8. Displacement maps of the lower surface for construction variants with support stiffness of 100 MPa

**Influence of two layer solution application**

Mechanical behavior of two layer track solution can be found in Fig. 7, 8 and 9. It is clearly shown that those variants are characterized by lower displacements. However, the comparison of stress maps (Fig. 9) for Variant 1 and 3 may lead into conclusion, that two-layer surface do not lead to reduction of stress in plates if there is not applied PFJ. It should be also mentioned that anti-vibration mat stiffness influences stress distribution and structure deformation as well as stress transfer to the ground, thus this aspect should be recognized in future analysis.
Conclusions

Analysis of presented results may lead to following conclusions:
• PFJ usage in analyzed tram pavement slabs significantly reduces ground pressure distribution. Maximum displacement of ground under the track system in analyzed example is reduced by about 35%
• PFJ usage reduces maximum stresses in tram surfaces, in the analyzed example it is reduced by about 30%
• Two-layer solution of tram track leads to significant displacement reduction of about 30% in comparison to the one-layer system
• Two-layer solution application without PFJ may lead to displacement reduction of similar value as one-layer solution with PFJ. The best result are obtained for variants with two-layers and PFJ connections
• The stiffness of anti-vibration mat should be responsibly chosen in order to avoid big deflections of upper layer.

This numerical research should be continued by analysis taking into account more complex load combinations. Also the numerical results should be confirmed by complex *in situ* tests.
Abstract

This work presents results of numerical analysis of tram tracks constructed in four different variants. There have been analyzed the influence of Polymer Flexible Joint Technology on displacement reduction in concrete tram slabs subjected by high loads coming from trams. There is also shown ground pressure distribution in author’s original solution variant of two-layer tram construction. The resultant stress and displacement maps are shown and conclusions are drawn.

Keywords: concrete, displacement, Polymer Flexible Joint, tram track

ZASTOSOWANIE POLIMEROWEGO ZŁĄCZA PODATNEGO W NAWIERZCHNIACH TRAMWAJOWYCH

Streszczenie

Praca przedstawia wyniki analizy numerycznej czterech wariantów konstrukcyjnych nawierzchni tramwajowej. Celem obliczeń jest określenie wpływu zastosowania Polimerowego Złącza Podatnego na redukcję przemieszczeń w betonowych płytach nawierzchniowych poddanym dużym obciążeniom pochodzącym od kół tramwajów. W pracy pokazano również porównanie rozkładów ciśnień od gruntu w nawierzchniach konstruowanych tradycyjnie oraz w sposób dwuwarstwowy, będący rozwiązaniem jednego z autorów. Przedstawiono mapy naprężeń i przemieszczeń oraz wyciągnięto wnioski.

Słowa kluczowe: beton, przemieszczenie, Polimerowe Złącze Podatne, nawierzchnia tramwajowa

References


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