USE OF EXPANDED POLYSTYRENE (EPS) SUB-BASE IN RAILWAY TRACK DESIGN

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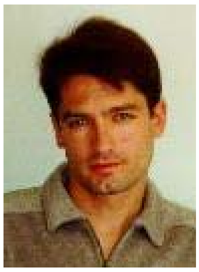

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Summary

The paper presents results of a study on feasibility of Expanded Polystyrene (EPS) material in a railway track design. In this research, performance of a slab track structure with an EPS layer between the slab and subsoil in a high-speed application has been investigated.

The dynamic behavior such the track structure in high-speed applications has been analyzed using RAIL software (TU Delft). An optimization on material properties of EPS, slab thickness and stiffness of subsoil has been performed. The optimization criteria are minimization of the 'dead' weight of a track structure and the costs related to the sub-grade improvement (i.e. the vertical stiffness of the subsoil should be as low as possible) while imposing constraints on the stresses in the EPS and subsoil layers.

A set of compromised optimum solutions has been obtained using a numerical optimization technique. The results have demonstrated feasibility and advantages of using EPS in high-speed slab track design especially on subsoil with poor vertical stiffness properties.

Keywords: EPS Geofoam Application, Railway Track Design, High-Speed Tracks, Multi-criteria Optimization

1 Introduction

Large areas of the densely-populated western and northern parts of The Netherlands consist of subsoil with geo-technical characteristics ranging from poor to very poor. Building of railway structures under these conditions would require a substantial improvement of the bearing capacity. The conventional approach consists of replacing a great deal of the poor soil by sand (sub-grade improvement). Even if pre-loading of a sub-grade layer is applied, relatively large settlements due to high weigh of a track structure are likely to occur during the initial phase of the structure's life. With the application of ultra-light materials, such as Expanded Polystyrene (EPS), a so-called "equilibrium" structure can be created, which would practically prevent the increase of grain stresses in the sub-grade. In other words, the weight of the track structure plus lightweight material should approximately compensate the weight of the excavated material. In this paper a slab railway track based on the Rheda 2000 system is considered. To reduce the total weight of a structure and consequently stresses in the sub-grade an EPS layer is applied between the slab and sub-grade.

As the behavior of a track structure has been analyzed, the next step is to optimize it. Here a numerical optimization technique developed at TU Delft has been used to minimize the 'dead' weight of a track structure as well as the costs related to the sub-grade improvement. The stiffness of EPS and soil has been varied during the optimization while imposing several constraints on maximum stresses in the components of a structure. The results of optimization are discussed in Chapter 3. Finally, some conclusions and recommendations on application of EPS in railway track design are given in Chapter 4.

2 Track Structure with an EPS Sub-base

In the light of the positive experiences with heavy-duty lightweight pavement structures, TU Delft decided to investigate the possibilities and conditions for the application of an EPS sub-base in both ballasted and non-ballasted track structures [9]. The density of EPS is directly related to its Young's modulus and other material characteristics. The mechanical properties of EPS were taken from [1] according to which the Young's modulus E_{EPS} of EPS could be approximated by the function

$$E_{eps} = A\rho_{eps}^{B} \text{ [MPa]} \qquad (1)$$

where

ρ_{EPS} [kg/m^3] is the density of EPS;

$A = 0.1284$ and $B = 1.368$ are the parameters of the approximation.

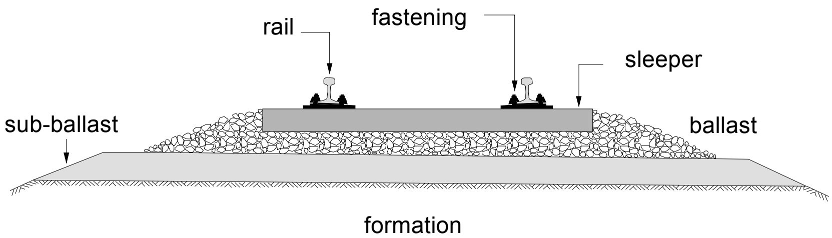

Figure 1 Classical railway track

In order to use EPS as a sub-base material in conventional track design (Figure 1) the concrete slab should to be placed under the ballast bed, since the ballast has no bending stiffness.

As compared to traditional sub-base materials, EPS has a very low density, Young's modulus, water absorption capacity and thermal conductivity. Because EPS has a relatively low strength, a concrete slab on top of the EPS layer is inevitable. In fact, this makes an integrated slab track solution very attractive. Because of relatively soft soil a sub-base layer in such structure usually consists of stiffer concrete roadbed and some base materials. The total weigh of the structure, which determines the level of stresses in the foundation, can be reduced by using EPS as sub-base material.

To feasibility study of using EPS in railway track design based on the analyses of the static and dynamic behavior of an Embedded Rail Structure (ERS) with an EPS sub-base layer has been performed in [9]. The numerical analyses have been done using GEOTRACK and RAIL software. Here the performance of a slab track structure based on Rheda 2000 system is investigated using an optimization technique. The dynamic behavior of the structure for high-speed operation is analyzed using RAIL software. Results of the optimization are discussed below.

3 Optimal Track Design with an EPS Sub-base

Probably, one of the most promising slab track designs called Rheda-2000 has been recently introduced in Germany. Such a structure consists of twin-block sleepers with lattice reinforcement, which are directly fastened to a concrete slab (Figure 2). An alternative design of a Rheda 2000 design has been suggested in [10] by applying the reinforcement closer to the top and bottom of a slab (in traditional Rheda-2000 the reinforcement is placed at the position of the neutral line). The bending stiffness of such slab is considerably higher as compared to the one in traditional Rheda-2000 design. Therefore, the supporting layer can be softer meaning that soil should be less improved or not improved at all.

Here, the modified Rheda-2000 with EPS sub-base (Figure 3) is used in the optimization. The optimization searches for a design that minimizes the total cost of the structure while satisfying some safety requirements. The objectives, constraints and design variables of the optimization problem are discussed below.

The total costs of the track can be reduced by eliminating or reducing the efforts related to soil improvement, which means that the stiffness of the foundation C_{gr} should be as low as possible, i.e. $C_{gr} \to \min$. By increasing the bending stiffness of a concrete slab, the stiffness of soil layer required for a safe operation can be reduced as well. The stiffness of a slab can be increased by for

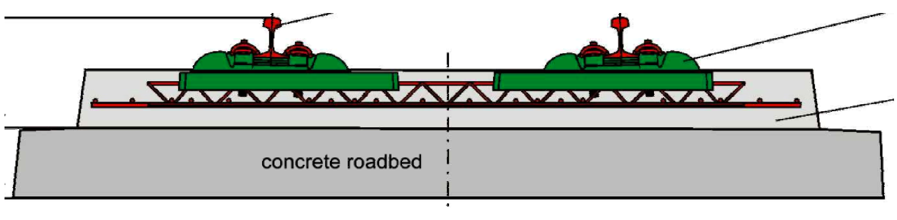

Figure 2 Cross-section of Rheda-2000 track design

example increasing the high of the slab h_{sl}. To prevent fatigue damage of the subsoil the stresses in foundation should be below the prescribed limits, i.e. $\sigma_{gr} \leq \sigma^*_{gr}$. The maximum allowable stress in foundation σ^*_{gr} can be calculated using the following empirical formula [2]:

$$\sigma^*_{gr} = \frac{0.006 \cdot C_{gr}}{1 + 0.7 \cdot \log(n_i)} \qquad (2)$$

where

C_{gr} is the dynamic elasticity modulus of foundation;

n_i is the number of cyclic loadings. In the calculations here $n_i = 2 \cdot 10^6$ loadings has been used.

Too soft foundation results in relatively large vertical displacements in a structure resulting in high bending moments in a concrete slab M_{sl}. To prevent the damage of the slab the bending moments should be restricted, i.e. $M_{sl} \leq M^*_{sl}$. The procedure for calculation of the maximum allowable stress in a concrete slab M^*_{sl} used here is described in [10]. It takes in to account:

- fatigue of concrete;
- fatigue of reinforcement steel.

The dynamic behavior of the track structure has been analyzed using RAIL software. The TGV train moving with the speed $v = 65\ m/s$ on the slab track with EPS sub-base layer has been simulated and the required responses of the track structure have been calculated. To prevent the damage of EPS layer the deformations ε_{eps} in the EPS layer have been prescribe to $\varepsilon_{eps} \leq \varepsilon^*_{eps} = 0.05$ (the height of the EPS layer is $1\ m$). The maximum displacements of rails u_{rail} due to the high-speed train should be below the maximum allowable displacement $u^*_{rail} = 2\ mm$ in order to prevent derailment, i.e. $u_{rail} \leq u^*_{rail}$. The limitations have also been imposed on the level of contact forces between wheel and rail in order to reduce damage of wheels and rails which ultimately results in reduction of the corresponding maintenance costs.

Design variable	**Lower bound**	**Upper bound**	**Initial value**	**Units**
C_{gr}	20	90	50	kN/m^3
w_{sl}	1.2	2.0	1.5	%

Table 1 Design variables and their limits

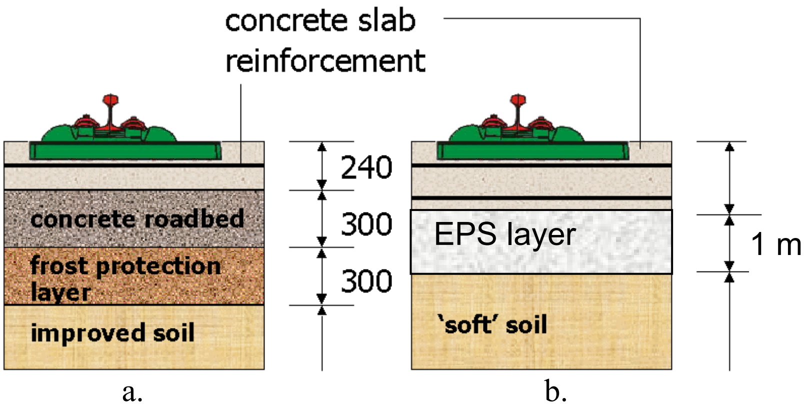

Figure 3 Traditional (a.) and modified (b.) Rheda 2000 track structure (one sleeper) with EPS

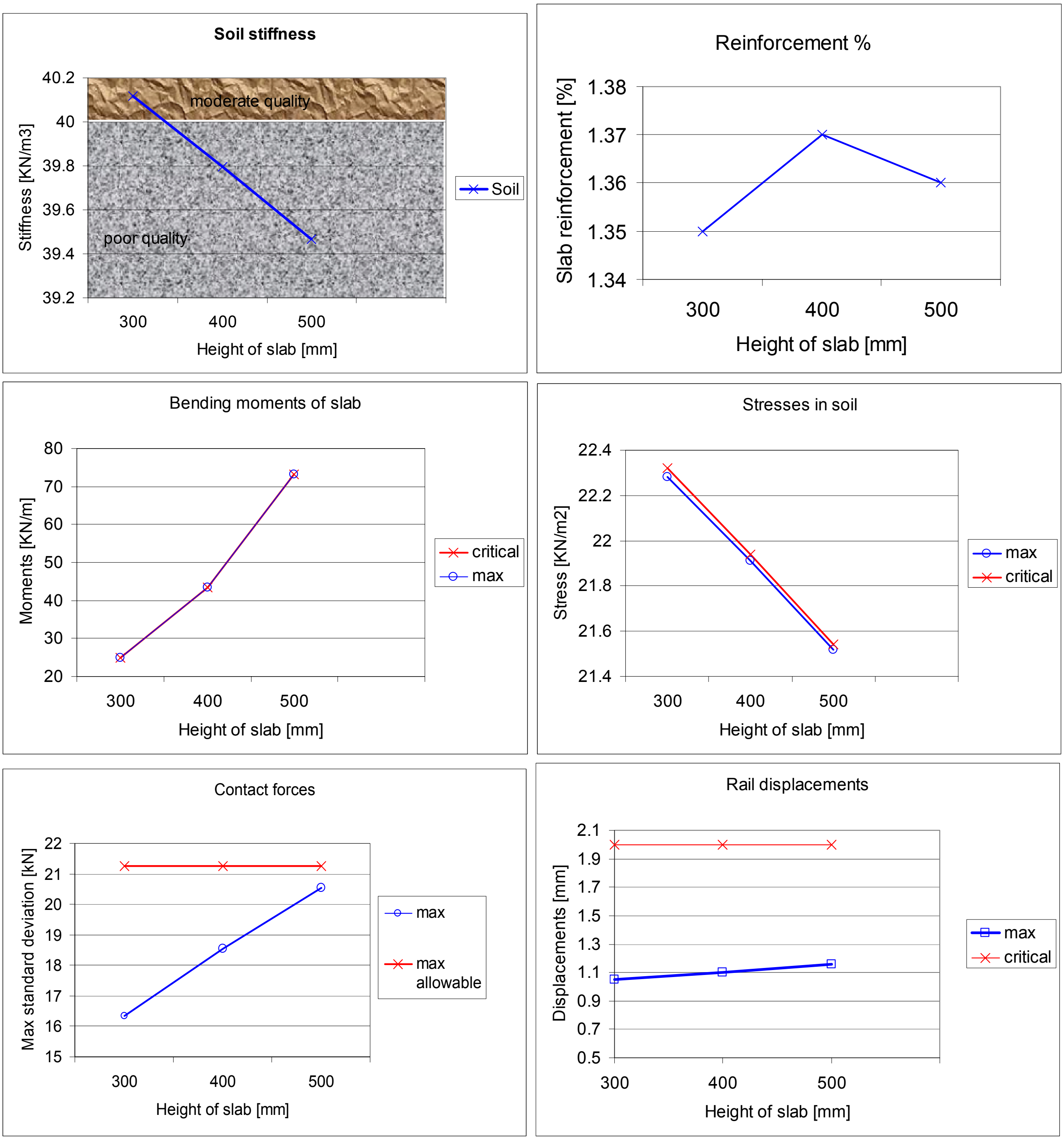

Figure 4 Results of optimisation

The density of EPS $\rho_{eps} = 25kN/m^3$ was constant during the optimization. To optimize the slab track the stiffness of the soil and the degree of reinforcement of the concrete slab, $x = [C_{gr}\ w_{sl}]^T$, have been varied. Their lower and upper bounds are given in Table 1.

A number of optimum solutions have been found for different slab heights (30, 40 and 50 cm) as shown in Figure 4. From this figure it can be seen that slab track with EPS can be applied on a soil with a very poor quality. The bending moment of slab and stresses in soil are decisive response quantities since the corresponding constraints are active in the optimal solutions, which means that the slab and foundation are performing optimally (fully stressed design).

4 Remarks and conclusions

EPS can be applied in any track structure, but significant advantages will be derived when used on subsoil with a poor bearing capacity. In two special cases [9] – transition between engineering structure and plain track, and when constructing a track doubling – the advantages of EPS to avoid differential settlements may be even more evident.

In the case of very compressible subsoil, an EPS sub-base was found to be among the cheapest solutions, as maintenance costs would be reduced significantly. This sub-base type would certainly be better for the environment, both during construction and in service.

Based on the research described in this article, the following recommendations could be made:

1. Tests would be needed to obtain a better insight into the dynamic performance of a track with an EPS sub-base, especially with respect to the damping characteristics.
2. A test track with an EPS sub-base would be preferable for studying the performance under operating conditions.
3. It is advised to formulate uniform design criteria for the use of EPS in railway structures.

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