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Sustainable upgrading of fine-grained soils present in the right-of-way of High Speed Rail projects

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HIGHLIGHTS

- We model the stresses in the subgrade of a structure of High Speed Rails.
- The levels of the stresses in the capping layer have been calculated.
- They are compatible with mechanical fatigue of stabilized fine-grained soils.
- A thickness for capping layers made with treated materials is proposed.

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ABSTRACT

The upgrading of *in situ* fine grained soils treated with lime and/or hydraulic binders for a use as subgrade in common infrastructures of civil engineering is a process in accordance with sustainable development. But in the case of the projects of High Speed Rail (HSR), the expected life of structures and the stresses caused by traffic have led to ask about the fatigue mechanical behavior of these materials. Currently, because of the lack of knowledge, they are landfilled. In this paper, numerical modeling of the HSR infrastructure allows determining stresses in the structure. By combining these results with fatigue behavior, it is possible to estimate the thickness of the capping layer using treated materials. This process highlights that fine grained soils present in the right-of-way of HSR projects can be upgraded and used as materials for the capping layer.

1. Introduction

The *in situ* soils present in the right-of-way of civil engineering projects have generally mechanical characteristics inconsistent with stress rates generated by the infrastructure they have to support. To upgrade these materials by using them in subgrade layers, it is common to mix them with a few percent of hydraulic binders to improve their mechanical performances [7,16,12]. Besides, this process has the advantage to minimize the environmental impact and to reduce the economic cost of the infrastructures [35,41,25,36,37,29].

This approach is widely used in numerous civil engineering applications such as road construction, embankments, foundations, slabs and piles [5,4,21]. In the French railway sector, soil treatment in HSR capping layers is strongly discouraged [39], due to the expected life of railways structures (one hundred years) and the stresses caused by High Speed Rails (HSRs) traffic that lead to ask about the fatigue mechanical behavior of treated materials. To date, this process has been used only on several kilometers of line in France for experiments [18,26] and at the present time, in classic HSR projects, the *in situ* materials that do not have sufficient characteristics are stripped, landfilled and substituted by quarries materials.

Based on numerical calculations and on the approach followed in the road sector where the fatigue criterion is characterized by the maximum tensile stress at the bottom of the capping layer [34,2], the aims of this paper are to:

– Demonstrate that treated materials can be considered for their use for the capping layer of HSR structures instead of the granular solution.
– Suggest an optimal thickness to these layers in function of the mechanical fatigue strength of treated materials.

First a modeling by Finite Element Method (FEM) of the entire structure is performed to determine the load distribution under the ties. This type of model is not practical for geometrical para-

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metric studies due to complex preprocessing and high computing resources. Therefore this load distribution is then used as input of a semi-analytical model. This model is dedicated for the study of transport infrastructures seen as a stack of layers. The differences in the results for the tensile stress at the bottom of the capping layer given by the two approaches are discussed. Then by testing different thickness, the optimal geometry of the capping layer using treated materials for which fatigue behavior has been characterized [45,17,8,22] is determined.

2. Materials and methods

2.1. Modeling

2.1.1. CESAR-LCPC

CESAR-LCPC [28,46] is a FEM software dedicated to civil engineering (structural analysis, soils and rocks mechanics, thermal, hydrology, etc.). This software can model complex structures and solve various problems (mechanical calculation of structures, stresses in concrete at an early age, etc.). Calculations are done in linear elasticity and static mode.

2.1.2. ViscoRoute© 2.0

The software ViscoRoute© 2.0 [11,10,14] is based on semi-analytical methods and a model of semi-infinite multilayered structure. The mechanical behavior of layers can be considered as elastic or thermoviscoelastic, according to the Huet and Sayegh law [27,42]. Note that this software cannot model other structures than those composed of semi-infinite layers (involving rails and ties).

2.2. Structures studied

For the FEM modeling, along the *Z* direction, the entire railway structure is modeled. Due to symmetry conditions, along both *X* and *Y* directions, only one quarter of the structure is modeled. It is meshed by extrusion using quadratic T6 and Q8 elements (Fig. 1a). The structure complies with the requirements of French standard for the construction of HSR structure [39]. The track bed has a Young's modulus equal to 70 MPa, a constant density of 2000 kg m^{-3}, a constant Poisson's ratio of 0.25 and a thickness of 2000 mm. The treated capping layer rests directly on the track bed. To represent a wide range of treated materials and to take into account their mechanical kinetic evolution in time [26,31] three Young's modulus (100, 5000 and 10,000 MPa) were selected. Two thicknesses (400 and 300 mm) corresponding to usual thicknesses for capping layers were considered. On the capping layer is laid an unbound granular sub-layer (ρ = 2000 kg m^{-3}, E = 70 MPa, ν = 0.25). The upper layer is the ballast. The ballast is divided in two zones. The first zone is constituted of compact ballast under the ties with a Young's modulus of 200 MPa, a density of 1700 kg m^{-3} and a Poisson's ratio of 0.4 [23] and a second zone of loose ballast around the ties [6] with a Young's modulus of 8 MPa, a density of 1300 kg m^{-3} and a Poisson's ratio of 0.2. The concrete ties are embedded in the ballast. They have a density of 2400 kg m^{-3}, a modulus of 34,000 MPa and Poisson's ratio of 0.2 and support the rails made up with 60 El rails profile. For the sake of simplicity, the rail is modeled by a rectangular section of width equal to the real rail (150 mm). The height of 134 mm was determined to keep an equivalent second moment of area. The density, the Young's modulus and the Poisson's ratio of the rail are respectively 7800 kg m^{-3}, 210,000 MPa and 0.28.

For the semi-analytical modeling, the layers are modeled by semi-infinite layers (Fig. 1b). The track bed, the sub-layer and the ballast keep the same properties as explain above. For the capping layer, the density and the Poisson's ratio stay unchanged, but seven cases of Young's modulus and three thicknesses are studied. All the dimensions and mechanical characteristics are given in Table 1.

2.3. Loadings

For the FEM modeling, the considered loading is a bogie with two axles spaced 3 m apart. It is assumed that two different bogies do not affect each other in terms of mechanical responses due to the large distance between them (18.7 m). Each axle static load is 170 kN. To consider the dynamic effects and rails defects, the general method is to empirically express the dynamic load as the static load multiplied by a dynamic amplification factor [3,24,13,23]. In this study, a coefficient of 1.5, commonly used for new HSR infrastructures, is applied to the loading. [20,40,9].

As a result, wheel load is modeled as a static linear pressure which the resultant load R is 127.5 kN placed in the middle of the tie T8 (Fig. 1a) and distributed along the rail width (nine nodes) at 1.5 m from the symmetry axis. It can be shown that this loading position on the rail is the worst in terms of tensile stress at the bottom of the capping layer [38].

3. Results

3.1. Modeling

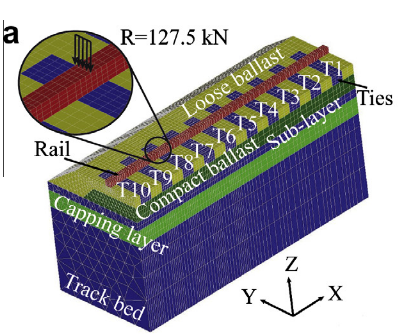
3.1.1. Load distribution under ties

Fig. 2a shows the load distributions under the most stressed ties close to one axle of the bogie, for the three levels of modulus of the capping layer (100, 5000 and 10,000 MPa) for str1 and with a modulus of 10,000 MPa for str3. The load is distributed principally on five ties, and is almost symmetrical. The tie T8 below the point of application of the load takes between 43.8% and 47.8% of the load, depending on the capping layer modulus. The thickness of the capping layer does not affect the load distribution since the difference between str1 and str3 are negligible (<1%). Ties on either side (T7 and T9) support about 22% of the load, independently of the modulus. The other two ties (T6 and T10) support only a small load (4–8%), and increasing the modulus significantly reduces their load value. The other ties show a level of load lower than 4% of the total load. These load distributions are consistent with literature [15]. The marking result is thus that the increase of the capping layer stiffness has only a slight effect on the load distribution. Moreover higher the modulus, higher the loading under the central tie T8. Therefore, in the rest of the study, only the load distribution corresponding to str1 with a modulus of 10,000 MPa is considered.

The transversal stress variation under the most stressed ties T6, T7 and T8 is given in Fig. 2b. The center of the tie is less stressed than the edge. The load under T8 varies from 53.4 to 33.0 kN m^{-1}, from 26.9 to 14.4 kN m^{-1} for T7 and from 6.3 to 2.3 kN m^{-1} for T6.

To input these results in the ViscoRoute© 2.0 calculations, the load distributions must be described with a constant stress (vertical or horizontal) applied on rectangular or elliptical surfaces. Therefore the load distribution under each half tie obtained with CESAR-LCPC has been discretized into five rectangular zones, to take into account the transversal stress variation (Fig. 3). The distribution of the total load on the different loaded rectangular surfaces adopted in ViscoRoute© 2.0 is given in percent in Fig. 3.

a



b

Ballast	E = 200 MPa ν = 0.4	350 mm
Sub-layer	E = 70 MPa ν = 0.25	200 mm
Capping layer	E = 100, 500, 1000, 2000, 5000,7000 and 10 000 MPa ν = 0.25	400 mm - str1 350 mm - str2 300 mm - str3
Track bed	E = 70 MPa ν = 0.25	2000 mm

Fig. 1. (a) Modeled structure with CESAR-LCPC; (b) modeled structure with ViscoRoute©2.0.