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Soil-binder columns for the rehabilitation of railway track platforms

Colonnes de sol traité pour la réhabilitation de plateformes ferroviaires

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ABSTRACT: Railway track reinforcement using soil-binder columns without removing track structure can be an efficient method to rehabilitate old lines. This work presents results of a study on a reinforcing method of old railway track platforms with poor bearing conditions. It consists in drilling through the ballast layer and injecting binders into the soil to form short columns in the track subgrade. Experimental injection testing has been successful in demonstrating the feasibility of the method, in that it was possible to inject the grout below the ballast layer and to create soil-binder columns with diameters ranging from 30 to 60 cm, depending on the injection parameters, for the different tested soils. The results of the numerical modelling of tested reinforcement configurations suggest that the columns provide a reduction of the deviator stress at the top of the platform in untreated soil areas between the columns. Therefore, the approach helps to mitigate typical and undesirable phenomena of old railway platforms such as progressive shear failure and excessive accumulation of plastic deformation at the ballast-platform interface. To validate the method even further, cyclic loading tests on true scale physical models are currently underway to study the resilient and permanent deformation of railway tracks with poor bearing conditions, submitted to the reinforcement method.

RÉSUMÉ: Le renforcement de la voie ferrée utilisant des colonnes de sol traité aux liants sans enlever les éléments de la voie peut être un moyen efficace de réhabiliter les lignes anciennes. Ce travail présente les résultats d'une étude sur une méthode de renforcement d'anciennes plates-formes de voie ferrée avec des conditions de portance médiocres. Elle consiste à forer à travers la couche de ballast et à injecter des liants dans le sol pour former de colonnes courtes dans la plate-forme. Les tests d'injection expérimentales ont permis de démontrer la faisabilité de la méthode, en ce sens qu'il était possible d'injecter le coulis sous la couche de ballast et de créer des colonnes de liant de sol avec des diamètres allant de 30 à 60 cm, en fonction des paramètres d'injection, pour les différents sols testés. Les résultats de la modélisation numérique des configurations de renforcement testées suggèrent que les colonnes fournissent une réduction du déviateur de contrainte au sommet de la plate-forme dans les zones de sol non traitées situées entre les colonnes. Par conséquent, cette approche permet d'atténuer les phénomènes typiques et indésirables des anciennes plates-formes ferroviaires, tels que l'échec de cisaillement progressif et l'accumulation excessive de déformations plastiques à l'interface ballast-plate-forme. Pour valider encore plus la méthode, des essais de chargement cyclique sur des modèles physiques à l'échelle réelle sont actuellement en cours afin d'étudier la déformation permanente et résiliente de voies de chemin de fer présentant de mauvaises conditions de portance, soumises à la méthode de renforcement.

Keywords: Railway track; Subgrade reinforcement; Soil–binder columns.

1 INTRODUCTION

The rehabilitation and construction works for the reinforcement of old railway track platforms is a complex, time-consuming and costly process that often causes significant disturbances to normal train operation (Selig & Waters, 1994).

Although different reinforcement approaches have been used in the past (INNOTRACK, 2008, Indraratna et al., 2011, Li et al., 2016), from soil replacement to reinforcement with geosynthetics, only a few allow performing the treatment or applying the reinforcement with minimal hindrance to railway operation.

In this context, the reinforcement of the track foundation, through injection of binders, without removing the ballast layer or the track components, is of paramount importance. This approach is not new but it still poses challenges in terms of railway operation, construction processes and quality assurance. For example, according to Li et al. (2016), slurry injection in the track platform has been used on railways since the 80's and with mixed results.

One of the main drawbacks has been the difficulty to penetrate the slurry into the clay soils and achieve an adequate dispersion. Although reports indicate that the pressures used with this method cause hydraulic fracture of the soil, the dispersion of slurry is somewhat poor (Karol, 1983).

Soil mixing is another method with significant potential, which was studied in the EU project INNOTRACK (2008), (Kouby et al., 2010) using a smaller and modified drill to create vertical soil-cement columns with diameters of up to 700 mm to a depth up to 15 m (Melentijevic et al., 2013). The RUFEX project followed up that initiative and focused on industrializing a way of reinforcing the railway platforms in the French network (Calon et al., 2011).

In this paper, the authors present some results of a research project - GroutRail - currently underway in Portugal.

2 THE APPROACH

The GroutRail research project focuses on industrializing a reinforcing method of old railway track platforms with poor bearing conditions, considering shorter and shallower columns/inclusions, injected right below the ballast layer, using different injection techniques, with the aim to achieve high productivity and covering a wide range of platform geomaterials. The main innovation expected to achieve with this project is the capacity to execute 1-m long columns, with 0.4 to 0.6 m diameter, with injection times under 1 min. (per column) from an adapted railway vehicle, to allow the reestablishment of normal railway operation as soon as possible.

To validate this reinforcement approach and to obtain a deeper understanding of the challenges that these techniques imply, the research team has been developing different activities, including: i) experimental injection testing on physical models to determine the best parameters for each injection technique and for different platform material; ii) 3D FEM modelling of the dynamic train-track interaction considering the non-linearity of the geomaterials and different column reinforcement layouts; iii) conventional and advanced laboratory characterization of mixtures with different binders using cyclic load triaxial tests on large specimens (clay-lime – CL; clay-cement – CC and sand-cement - SC); iv) cyclic loading of railway track physical models, constructed to true scale in laboratory.

3 THE RESULTS

3.1 Experimental injection tests

Initial experimental injection tests were carried out to demonstrate the feasibility of the proposed injection method. To this aim, relatively small physical models (4×2×2 m) were constructed (Figure 1), which included a small segment of track on top. After some characterization tests, injections were performed on different

locations and with different injection parameters to form the soil-binder columns. It was demonstrated the feasibility to drill through the ballast layer and form short soil-binder columns with controlled geometry, depending on the injection parameters, for the different tested soils.

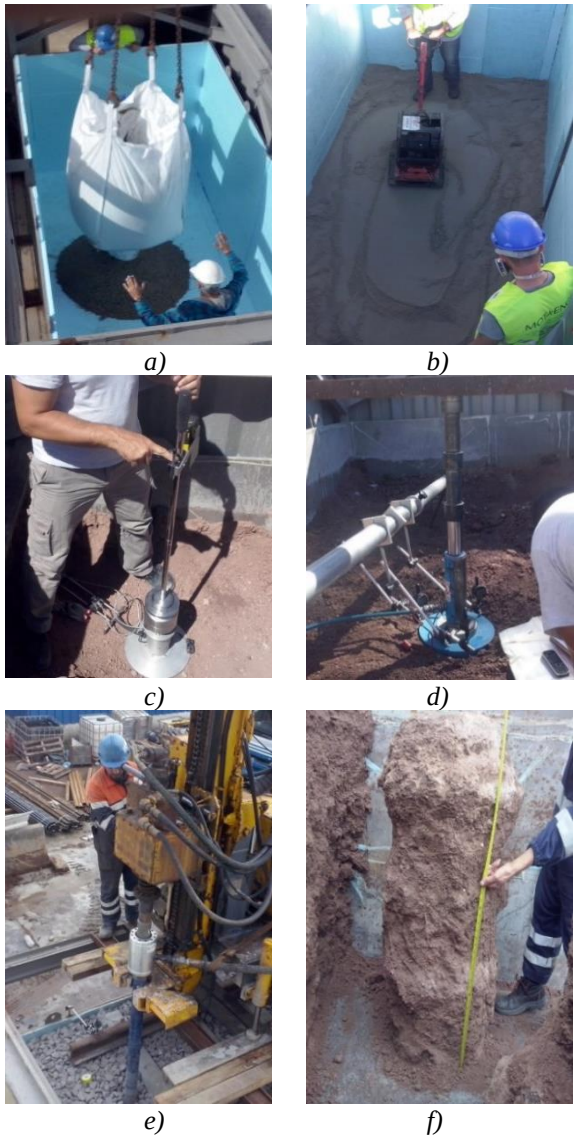

Figure 1. Stages of the initial experimental injection tests on the smaller physical models: a) filling the container; b) soil compaction; c) Handy Falling Weight Deflectometer Test; d) Plate Load Test, e) injections in the subgrade; f) soil-binder columns measured during the dismantling of the model

3.2 Numerical modelling

A parametric study was also performed comprising dynamic analyses using 3D FEM numerical models (Figure 2) to asses different aspects of the response of the train-track-subgrade system with the reinforcements, taking into account the non-linear behaviour of the geomaterials (Francisco et al., 2018).

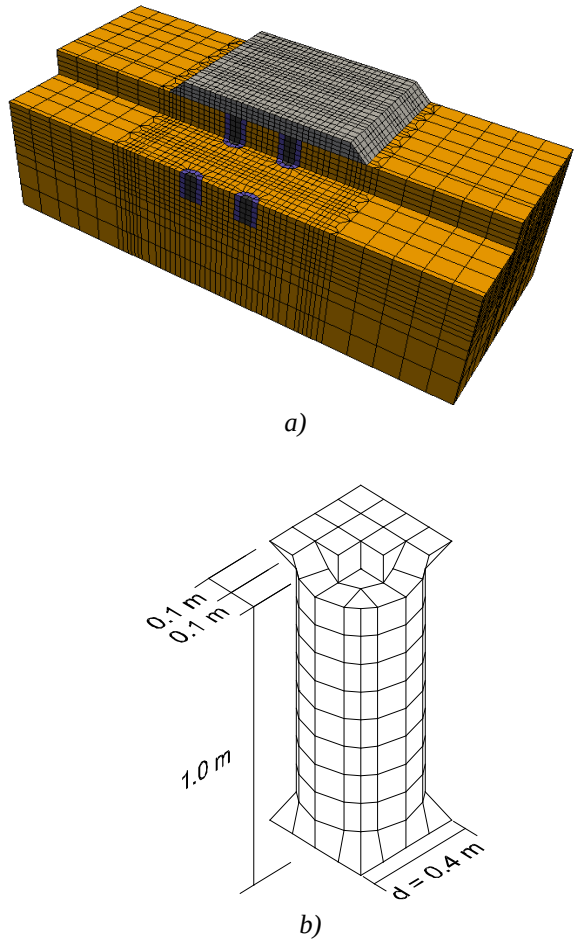

Figure 2. Partial view of the 3D FEM models: a) general view of the central zone; b) detailed mesh of the column (after Francisco et al., 2018)

Different column reinforcement layouts were tested in plan view (Figure 3) and the results suggested minor influence on the dynamic train-track interaction between the layouts.

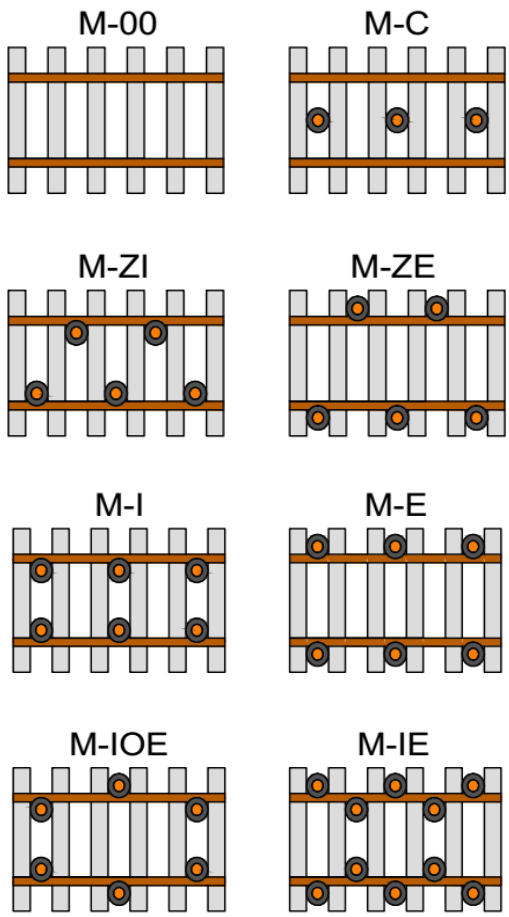

Figure 3. Tested column reinforcement layouts

On the other hand, columns at the track centreline should be avoided to prevent excessive tensions in the sleepers caused by negative bending moments.

Regarding the influence on the substructure, the columns seem to provide a reduction of the deviatoric stress at the top of the platform, in untreated soil areas between the columns, as identified in Figure 4 by the reddish colours.

Therefore, the approach is expected to help mitigate typical and undesirable phenomena of old railway platforms such as progressive shear failure and excessive accumulation of plastic deformation at the ballast-platform interface (Selig & Waters, 1994).

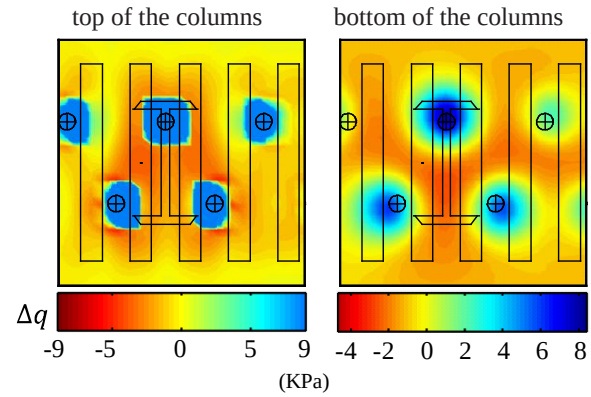

Figure 4. Changes in the deviatoric stress, Δq (with respect to the reference model with no reinforcements) in the platform due to the train-track interaction (after Francisco et al., 2018)

3.3 Laboratory characterisation

This research also comprises an extensive laboratory characterisation of soil-binder mixtures, namely, clay-lime (CL), clay-cement (CC) and sand-cement (SC) under triaxial cyclic loading, among other conventional tests.

The clay type soil is classified as clay of low plasticity (*CL*) and A-7-6, according to the unified classification system and to AASTHO, respectively. It is a fine soil, with 99.53% of material passing sieve No.200, Plastic limit of 26% and Liquid limit of 46% and with Optimum Proctor Modified (OPM) compaction soil density of 1.647 g/cm^3 and respective water content of 19.6%.

According to some Guidelines (Pinard et al., 2003, Little, 1995), the characteristics of this soil suggest that it may be treated with either cement or lime, which is of particular interest for the present study.

The sand type soil is classified as poorly graded sand (*SP*) and A-3, according to the unified classification system and to AASTHO, respectively. It is a granular material, with 2% of material passing sieve No.200, nonplastic and with Optimum Proctor Modified compaction soil density of 1.735 g/cm^3 and respective water content of 13.1%.

Figure 5 presents compression strength, R_c, results obtained on molded specimens of the tested soil-binder mixtures, considering curing ages of 2, 7 and 28 days.

It is clear the increase in strength provided by the cement, compared with the lime.

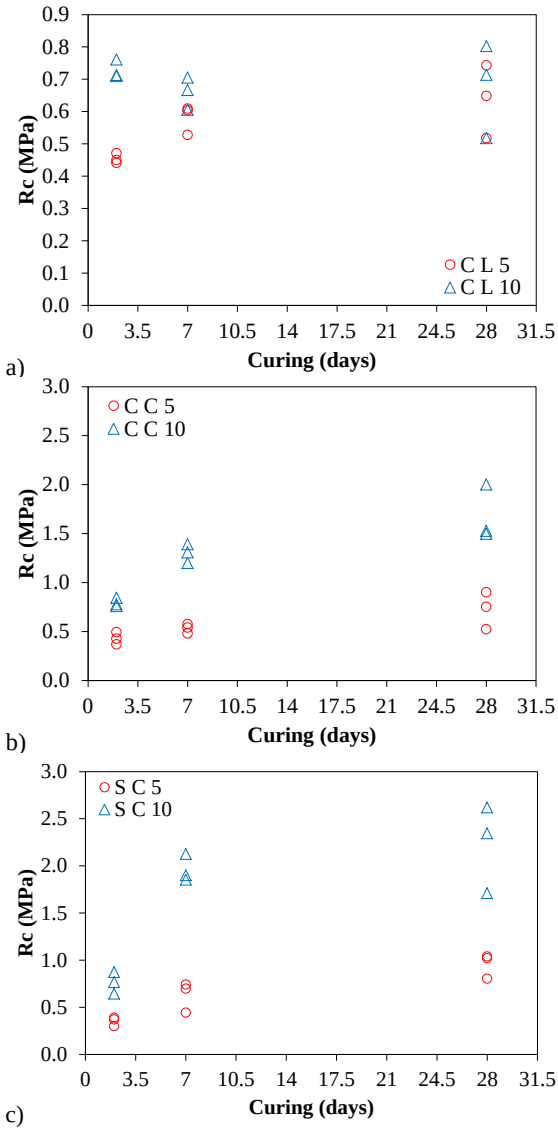

Figure 5. Results of the uniaxial compression tests on soil-binder specimens: a) Clay-lime (CL); b) Clay-cement (CC); c) Sand-cement (SC)

However, this increase is only significant for 7 and 28 days of curing. The obtained strength values indicate that the soils in question can be effectively treated with these binders.

Regarding the triaxial cyclic loading tests (Figure 6), large specimens were prepared (height: 0.4 m; diameter: 0.2 m) considering two binder contents (BC) of 5% and 10%, with degrees of compaction (Dc) between 80% and 100% OPM and different curing ages.

Figure 6. Aspects of the cyclic load triaxial testing: loading frame, specimen and chamber

The following main results were obtained:

i) the sand-cement mixtures showed better performance than the clay-lime and clay-cement mixtures, yielding higher resilient modulus (500-1800 MPa) and lower plastic deformations during the conditioning process of the specimens according to EN 13286-7 (CEN, 2004) (Figure 7); however, the results on the sand-cement mixtures suggested that good compaction is critical to achieve adequate behaviour - if it is not possible to adequately compact the mixture, more than 5% cement should be added;

ii) the results on the clay-lime and clay-cement mixtures were somewhat similar, with resilient modulus generally between 300 MPa and 700 MPa;

iii) compaction and curing are critical factors that influence the resilient behaviour of the clay-binder mixtures;

iv) there was marginal benefit in adding more than 5% of lime or cement to well compacted

mixtures - it is known that there is an optimal lime content when treating soils, which depends of the percentage of clay and its plasticity, among other aspects (Pinard et al., 2003).

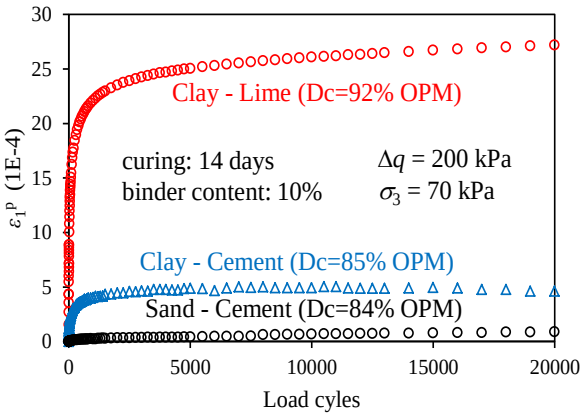

Figure 7. Some results of the cyclic load triaxial testing about the permanent deformation behaviour of the tested soil-binder mixtures

3.4 True scale physical modelling

To validate the reinforcement approach under study, this project also comprised cyclic loading tests on true scale physical models (or cells), each with dimensions 4.0×2.7×2.8 m.

Recently, four 4-m long track segments were constructed at LNEC's facilities to simulate different foundation scenarios of old railway lines, i.e. low compaction degree (80%<$Dc_{,OPM}$<90%) and low bearing capacity (E_{V2}<45 MPa) (UIC, 2008). Each cell was meant to test a different variable: injection parameter, column layout or geometry, soil and binder characteristics. After completing the injections in each cell (Figure 8a and b), the transducers are installed and a quasi-static cyclic loading of up to 200 kN is applied by a hydraulic system for about 500 thousand cycles (Figure 8c).

The planning and coordination of the tests has been quite challenging considering that it is only possible to reinforce and test one cell at a time to avoid testing cells with different curing times.

(a)

(b)

(c)

Figure 8. Aspects of true scale physical modelling: a) injection equipment; b) injections in the subgrade; c) instrumentation and cyclic loading tests on the physical model

Currently, the third physical model is being tested, so Figure 9 only presents the accumulated deformation (settlements measured on the rails in the loading area) of the first two tested structures:

i) the reference cell with no reinforcement;

ii) a cell with two soil-binder columns at every other sleeper spacing.

After roughly 500 thousand load cycles, the reinforced model showed settlement rates per cycle of about $1.0E^{-6}$ mm/cycle, while the nonreinforced model still evidenced $3.1E^{-6}$ mm/cycle.

These preliminary results evidence the benefit of the proposed approach in terms of limiting the accumulated plastic deformation assessed in terms of settlements measured at the rail level.

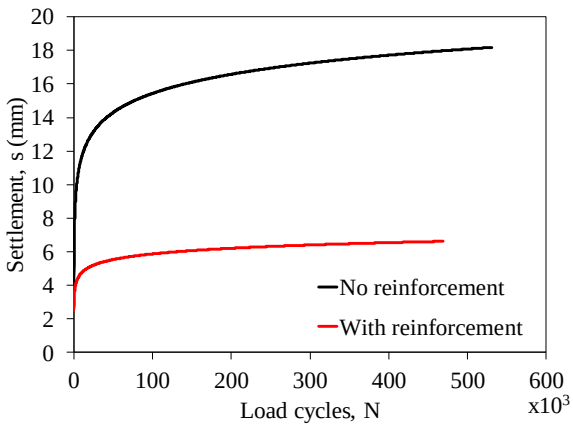

Figure 9. Accumulated deformation due to the cyclic loading on the physical models

4 CONCLUSIONS

Preliminary results suggest that such reinforcement approaches comprise alternative methods for the rehabilitation of old railway platforms, particularly in old and single-track lines.

The experimental injection testing has been successful in demonstrating the feasibility of the method, in that it was possible to inject the grout below the ballast layer and to create soil-binder columns, with diameters ranging from 30 to 60 cm, depending on the injection parameters.

The results of the numerical studies indicate that no significant influence on the dynamic train-track interaction is to be expected due to different column layouts.

Nevertheless, columns at the track centreline should be avoided, due to the development of higher tensions in the sleepers.

Further studies are needed to investigate the effects of the possible development of uneven track degradation due to columns placed in zigzag layouts.

Some results were analysed on the characterisation of soil-binder mixtures in cyclic load triaxial tests, which showed that compaction and curing are critical factors that influence the resilient behaviour of the mixtures.

The results suggest that there is only marginal benefit in adding more than 5% of binder to the soils considered in the laboratory study, particularly if the soils were adequately compacted.

In the framework of this research project, it will be necessary to further develop studies to analyse the cost-benefit ratios of the various reinforcement solutions applicable, in particular, to the column execution procedure (i.e. injection methods and parameters, materials involved) and the design of the solution (i.e. column geometry, configuration of the position of the columns in plan view).

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