STUDY OF THE MECHANICAL BEHAVIOUR OF THE BALLASTED TRACK USING DISCRETE ELEMENT METHODS

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ABSTRACT

In this paper, we are interested in the study of the ballasted track and specially in the mechanisms of degradation in the medium-to-long term of the ballast layer. Both an experimental and a numerical approach have been developed. Numerical simulations are performed using discrete element methods and are validated through comparisons with reference experiments at reduced scale. This principle is the basis of the study undertaken.

INTRODUCTION

Ballasted track is widely employed because of its mechanical properties and its flexibility. But the behaviour of the track and its components, such as the ballast layer, are still a poorly understood phenomenon. The stakes are significant for SNCF: a better comprehension of the mechanisms involved would make it possible to reduce the maintenance costs and to improve the ballast specification. We are interested on the mechanisms of degradation in the medium-to-long term of the ballast layer. A study was undertaken by SNCF in collaboration with research laboratories LCPC and LMGC. Principle and first results of this study are described in this paper.

1 – PRINCIPLE OF THE STUDY

The ballast behaviour can be studied using several approaches. First results were mainly empirical, issued from experience feedback of test runs, carried out in situ. These past years, many experimental researches were also carried out on bench facilities, with two different approaches: on one hand, standard tests, based on the soil mechanics, characterise the rheology of material but do not give any information on ballast behaviour in track, and on the other hand reference tests represent ballast under conditions that, although they are idealised, should be more realistic [4,1].

Ballast is often modelled as a continuous medium for which empirical constitutive laws should be available. Finite Element methods (FE) are then applied to solve the problem. Such a modelling should be relevant when considering the whole track system or the sub-ballast structure. However it is necessary to check the relevance of such an approach, since, the thickness of the ballast layer is only one ten grains under the sleepers.

Simulation methods resulting from research on the granular medium, referred as discrete element methods (DE) in opposition to FE methods, are an alternative approach. In this past years, researches on granular medium, especially numerical simulations, yielded significant results in Civil Engineering [2,6] which can be applied to railway problems. The DE approach is set at a microscopic level: the granular media is modelled grain by grain as a discrete system of perfectly rigid bodies in contact as shown in figure 1. During the evolution of the system, contact between grains can be created or disappear because of the motion of the grains. The interaction between grains follow laws of contact that can differ according to the DE model. DE methods enable us to analyse the microstructure of granular materials and to exhibit information which cannot be assessed in experiments or using FE methods: for example, the chains of forces, acting between grains are widely different from the distribution of stresses or strains commonly accepted in continuous media.

The numerical simulations are performed using a two-dimensional DE software, Contact Dynamics, developed at University of Montpellier with grains of polygonal form. Grains are perfectly rigid. Contact is modelled using an unilateral contact law with dry Coulomb friction. To solve the unilateral constraint problem, efficient numerical methods were developed (for more details see [5]).

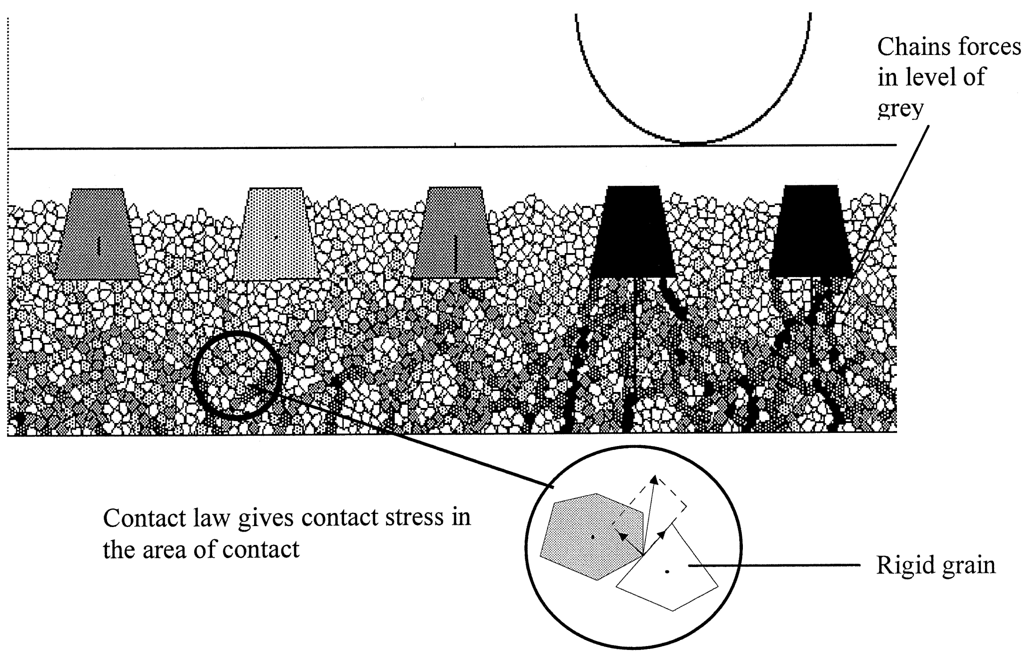

Figure 1 – Principle of the discrete element methods – Application to a two-dimensional model of a railway track in [5] .

Numerical simulations however require validation through comparison with some experiments. Reference experiments, which are simpler and less expensive than in situ experiments, are developed. Experimental parameters can be better controlled and more extensive results can be obtained.

These numerical and experimental approaches are the basis of studies undertaken: first, we focus on the ability of the numerical methods to reproduce the experimental results. This is a prerequisite to full scale test. This principle was successfully applied to study the ballast behaviour under vibrations during track tamping in a PhD Thesis [7,3].

2 – APPLICATION TO THE PROBLEM OF DEGRADATION OF THE TRACK

In this study, we investigate the ability of DE methods to predict the behaviour of a reference system, much simpler than real track, under quasi-static cyclic loading using the principle described below. The mechanisms that lead to the degradation of the ballast layer are investigated. The grains wearing (attrition and damage of points) is not studied. This work is undertaken in collaboration with University of Montpellier and LCPC and is preliminary to study more complex systems as real track.

2.1 –Experimental set-up

A reference experiment is developed at reduced scale and uses a two-dimensional material. The device is developed on the principle of Schneebeli materials that are often used in Civil Engineering to model the ground. These materials generally consisted on an assembly of piled up circular rolls. The experiment originality is the use of rolls of pentagonal section to model ballast grains. Rolls are made in cement with sufficient resistance, thus rolls are not damaged during tests. Grains of three different sizes (diameters of 10, 15 and 20 mm) are piled in a case so as to have about 10 cm of grains under the sleeper and to leave free edges as for a transverse section of track. An aluminium sleeper is put on rolls. To improve the lateral resistance of the sleeper, bars of square section have been fixed under the sleeper. An elastomer bed is laid on the case bottom to model the sub-ballast structure.

1000 cycles of vertical and lateral loading are applied to the sleeper using a pneumatic jack until reaching the structure collapse. A sinusoidal loading is applied under sleeper at a frequency of 0.25 Hz with different loading inclinations. A view of the experimental set-up is given figure 2.

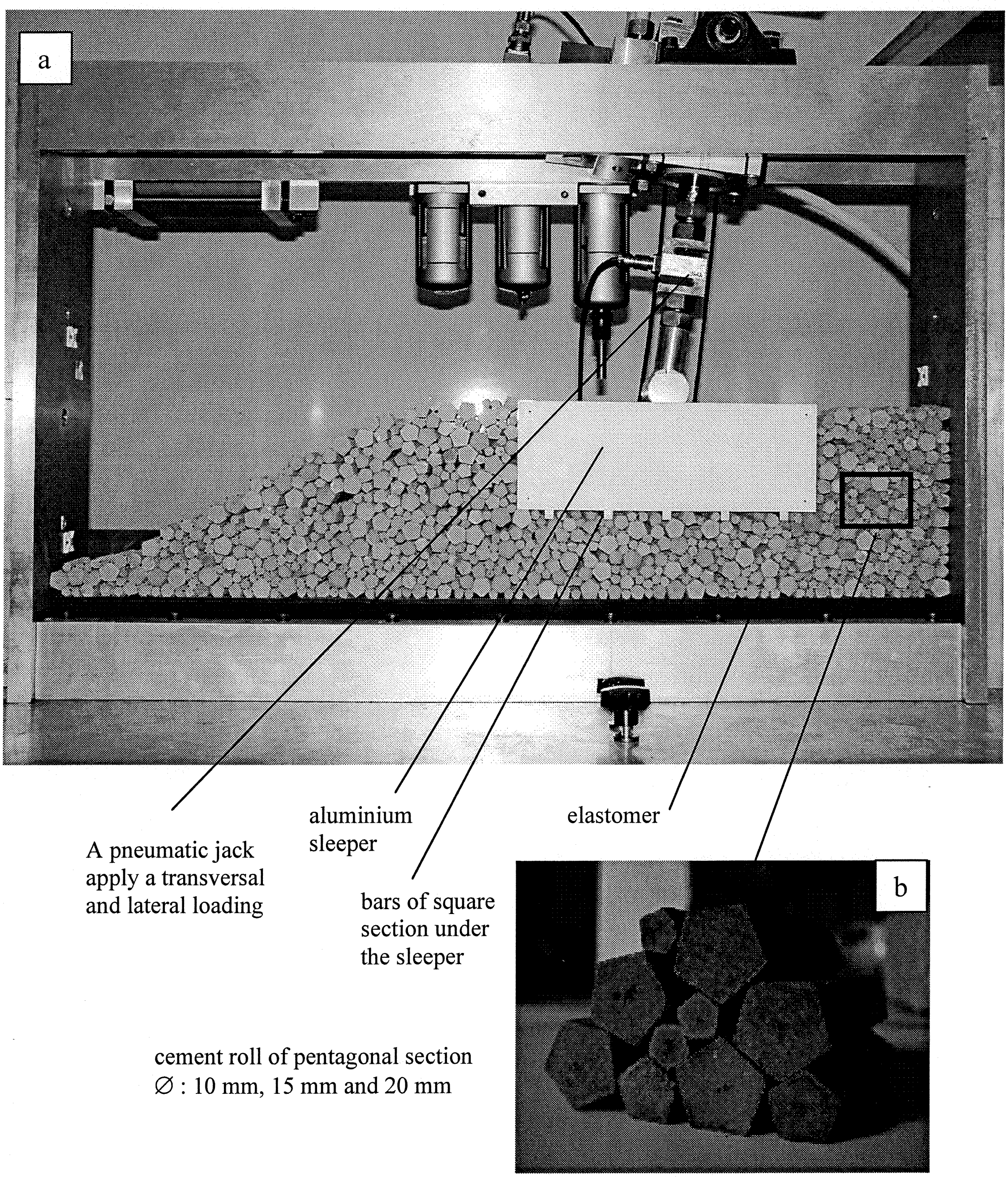

Figure 2: Reference experiment. View of the experimental set-up (a) and of the pentagonal rolls (b). A quasi-static vertical and transversal loading is applied until the collapse of the structure.

The displacement of the sleeper in the direction of the loading is recorded during the cycles using a displacement gauge to access the settlement of the sleeper. The loading intensity is also recorded. Images of the sleeper and of the rolls under the sleeper are captured using a digital camera at regular intervals. The positions of few rolls under the sleeper are recorded. Then cinematic of the rolls can be determined (see figure 3).

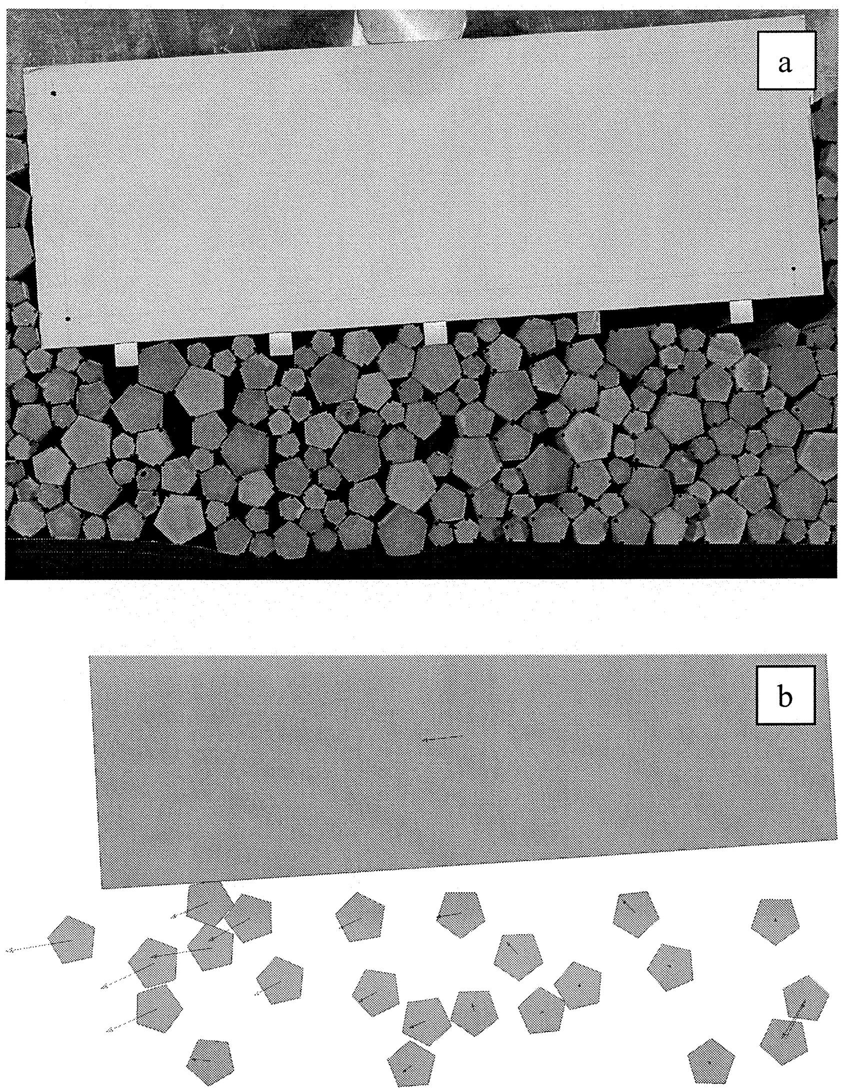

Figure 3 - Displacement of the grains after 1000 cycles of loading for a loading inclination of 15°.

2.2 – Experimental results

We observe the displacement of the sleeper and the rearrangement of few grains under the sleeper for different loading inclinations (0°, 5°, 10° and 15°). The behaviour depends on the loading inclination as expected.

It depends also strongly on the preparation of the sample. For a given loading inclination of 5°, we compare the displacement of two samples (figure 4): for a dense assembly (a), the deformation increment is important in the first cycles (densification) and is quite linear after whereas for a more loose assembly (b), we observe instabilities with abrupt rearrangements of grains. The stabilisation of the sample in applying a vertical loading preliminary to the test gives a more dense sample and lead to a more regular settlement. The influence of tamping quality and stabilisation on the transversal resistance is well known for real track.

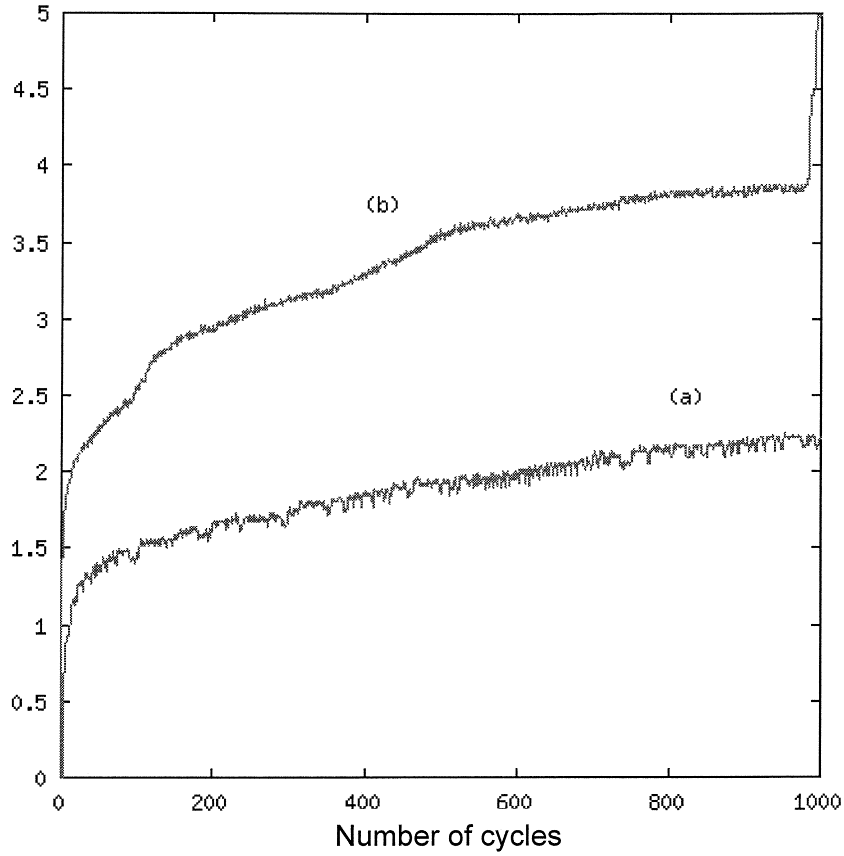

Figure 4 – Displacement of the sleeper versus the number of cycles for a dense assembly (a) and a loose assembly of rolls (b) and for a loading inclination of 5°.

It should be relevant to conduct more extensive experiments to provide a statistical approach of this phenomenon and to reach a critical loading inclination between stability of the assembly and non stability.

2.3 – Numerical simulations

The main difficulty in these simulations is to carry out a great number of loading cycles. Another difficulty is to determine the influence of small disturbances (due to error of modelling or numerical errors) on cycles of loading: if these disturbances are negligible for one loading cycle, it is not necessary the same for a thousand of loading cycles.

Numerically, the initial assembly of grains is prepared in producing a random rain of grains under gravity. The assembly is more and less dense according to the coefficient of friction.

In simulations, the cinematic of the sleeper is of same magnitude as in experiments. The behaviour of the assembly depends strongly of the loading inclination and of the initial density. In the future, we expect to use the experimental configurations in numerical simulations: thus, a better quantitative agreement can be expected with two-dimensional numerical simulations. In the figure, we show the displacement and contact force of the numerical assembly.

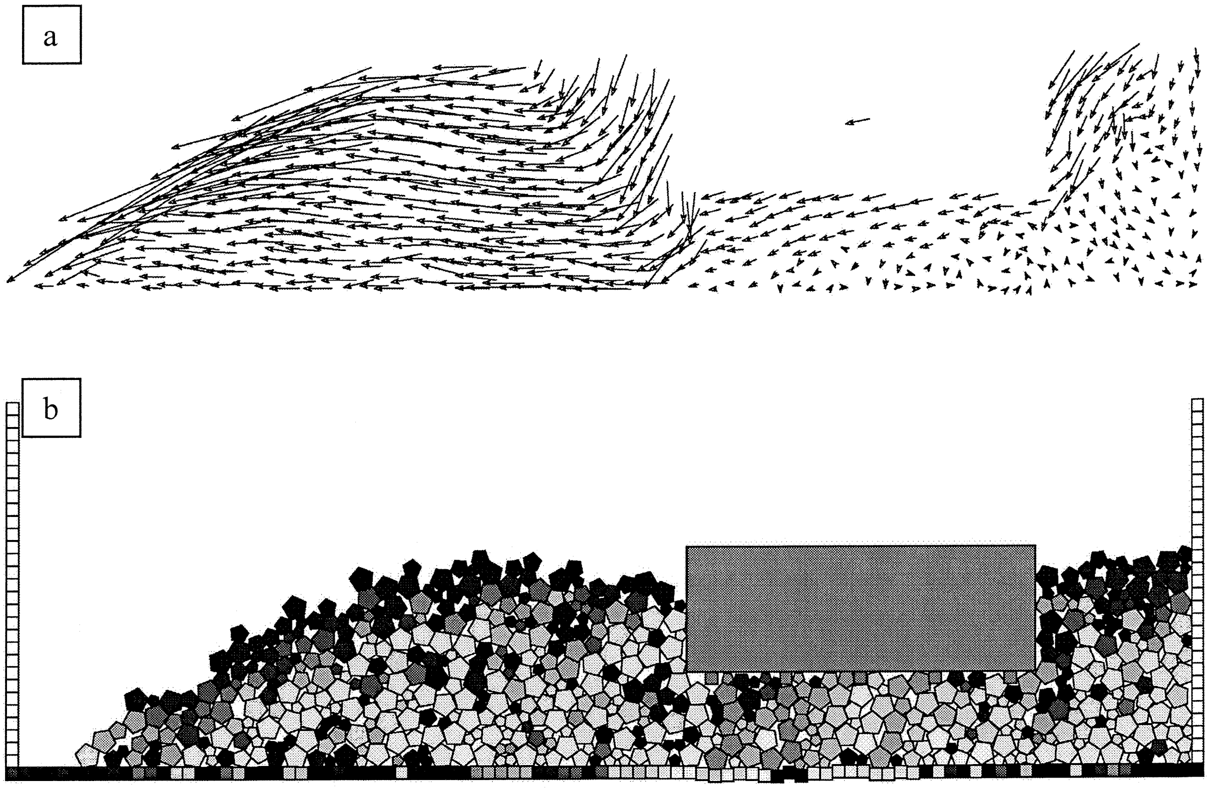

Figure 5: Displacement and contact force of the numerical assembly using Contact Dynamics.

In the first simulations, we observe that calculation cost appears quite important, about one month on an Unix station for an assembly of about 1000 grains. Moreover, the precision of the calculation is strongly correlated with the numerical parameters as time increment.

CONCLUSION

This study is a preliminary work necessary to determine if DE methods can be applied to predict the evolution of a granular medium on a great number of loading cycles. In the future, we expect to use experimental configurations in simulations to access a better quantitative agreement with experiments. But because of the calculation cost, it is not possible to study the settlement of the track during millions of cycles using this method. Nevertheless, the use of DE methods is valuable to study the behaviour of granular media such as ballast in the short to the medium term. A tridimensional DE software is under development using polyhedral particles.

Other studies are also undertaken at SNCF using a continuous approach. The aim is to model the ballast sub-structure using finite element methods. This approach is relevant for this problem. In the future, we expect to use both DE and continuous approach to model the all infrastructure.

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