

STUDY OF THE MECHANICAL BEHAVIOUR OF THE BALLAST USING DISCRETE APPROACH

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Abstract: In this paper, we are interested in the study of the ballasted track and specially in two main topics: the mechanisms of degradation in the medium-to-long term and the maintenance 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 studies undertaken.

Key words: ballast, granular materials, tamping, settlement.

INTRODUCTION

Ballasted track is widely employed because of its mechanical properties and its flexibility. But the behavior 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 two main topics: the mechanisms of degradation in the medium-to-long term and the maintenance of the ballast layer. Several studies were undertaken by SNCF in collaboration with research laboratories. Principle of these studies are described in this paper.

1 – PRINCIPLE OF THE STUDIES

The ballast behavior can be studied using several approaches. First results were mainly empirical, issued from experience feedbacks 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, characterize the rheology of material but do not give any information on ballast behavior in track, and on the

other hand reference tests represent ballast under conditions that, although they are idealized, should be more realistic [3,1].

Ballast is often modeled 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 modeling should be relevant when considering the whole track system. 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 [2,5] which can be applied to railway problems. In DE approaches, the material is modeled grain by grain as a discrete system of rigid bodies in contact. 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: in this paper, two DE methods are presented. DE methods enable us to analyze 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...

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, and are a prerequisite to full scale tests.

2 – APPLICATION TO THE MAINTENANCE OF THE TRACK

Ballast behavior under vibrations, during track tamping, has been studied. Better understanding of tamping mechanisms would enable us to reduce the maintenance costs in the long term. This work was implemented within the framework of a PhD. Thesis [6] carried out in collaboration with ENPC using both numerical and experimental approaches. A micromechanical model and a DE software has been developed, as well as a reference experiment.

A two-dimensional micromechanical model was developed to simulate the ballast behavior. Ballast is modeled as a two-dimensional assembly of convex polygonal grains. Each grain is assumed to be a rigid body but grains can overlap slightly with each other at contact points. Overlapping is understood as a deformation at the contact. The contact force acting between the grains is explicitly defined using this deformation, also taking into account the effect of friction. Thus, forces acting on each grain due to contacts or other actions such as gravity can be calculated. In computer code, the motion equations for each grain can be solved, thus determining the system evolution. This approach is commonly known as Molecular Dynamic. The micromechanical model was implemented in a DE software and was successfully used to solve Civil Engineering problems such as biaxial tests [6].

An experimental set-up at a reduced scale (1/3) was carried out in laboratory: in a rigid case, ballast, a portion of sleeper are piled (see figure 1). This device reproduces the action of tamping on ballast. In this experiment, two types of loading are applied: vibrations of a the tamper (one of the main tamping parameters) and a tightening force applied by continuous displacement of the case (see figure 1). These loading are applied separately (which is different of real tamping) for a better control of the experiment. Other operations such as the tamper going down into ballast are not reproduced in this experiment. Ballast behavior under the sleeper is observed and one measures the settlement of ballast under the sleeper as well as the force applied during the test. We can notice that this reduced scale experiment imposes the respect of law of similarities in acceleration.

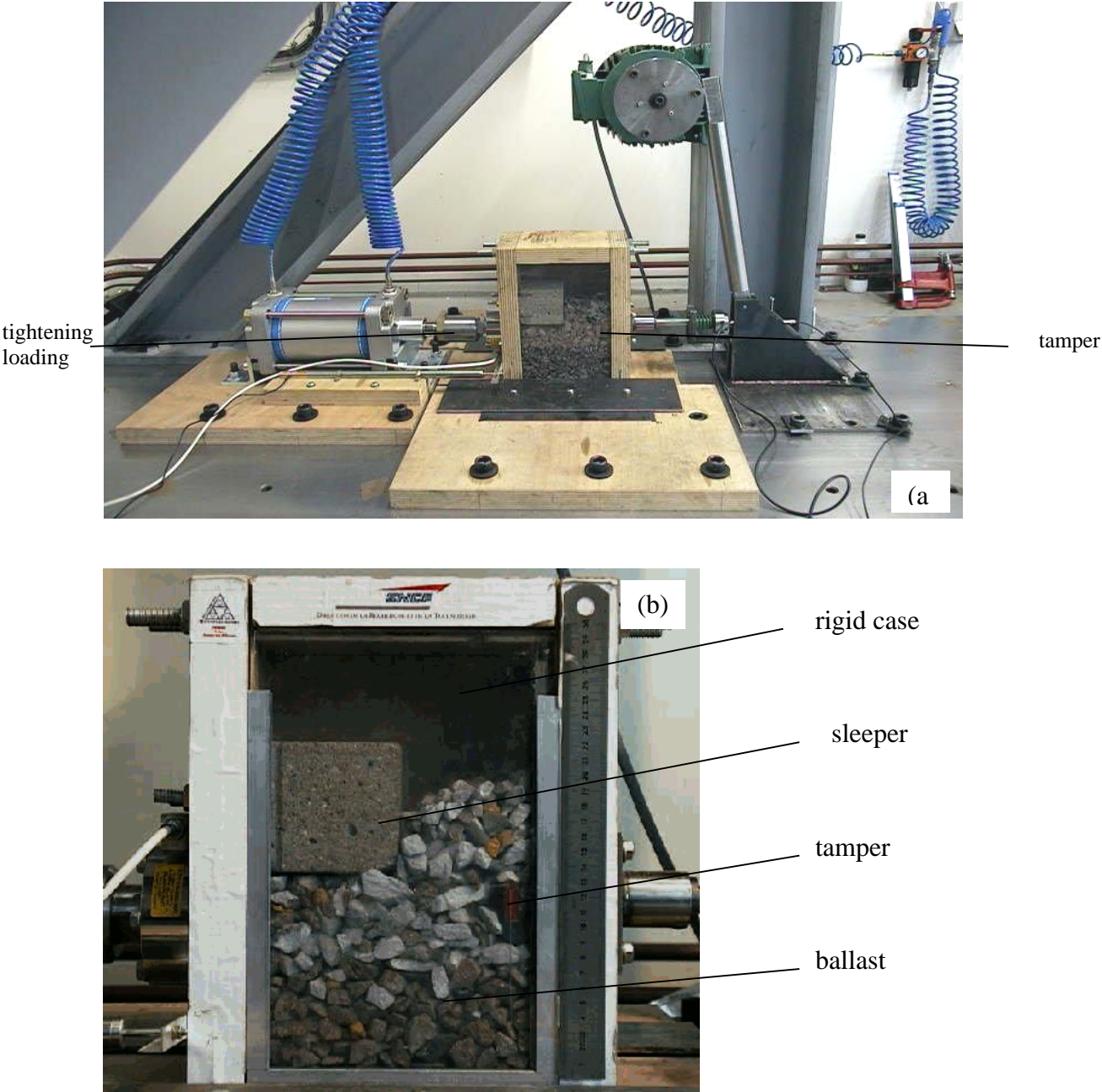


Figure 1 : (a) View of the tamping experimental set-up – (b) Rigid case with ballast, a portion of sleeper and a tamper.

RESULTS

Experimental studies make it possible to define tamping quality standards, which are:

- ✓ the quality of the contact between the sleeper lower surface and ballast. The surface of contact must be continuous and regular to get a maximum surface of contact thus making it possible to better distribute the efforts.
- ✓ The sample density under the sleeper. Ballast have to be compacted enough.

These two criteria were checked during the experiments in order to determine the set of parameters that would lead to an optimal tamping over time.

In these experiments, we highlight the frequency influence. Three different behaviors were observed depending on the frequency. The curve (figure 2) gives the tightening force versus the test duration (for a better intelligibility, curves are shifted in time). We observe:

- ✓ a stiff behavior at low frequencies: the grains motion is mainly due to the tightening loading effect, and movement is done by jolt. Vibrations effect are localized around the tamper and not very significant. The surface of contact between the sleeper and ballast is not homogeneous and the sample is not very densified.
- ✓ a liquid behavior at high frequencies: vibrations effects are very significant, ballast opposes therefore little resistance to the tightening loading. Grains undergo great displacements. The surface of contact between ballast and sleeper is relatively homogeneous but the sample is slightly compacted.
- ✓ a viscous behavior at intermediate frequency: for this range of frequencies, vibrations and tightening force have the same importance. Vibrations are sufficiently significant to allow the tamper penetration during tamping. The surface of contact is homogeneous and the sample is better densified than in the other tests.

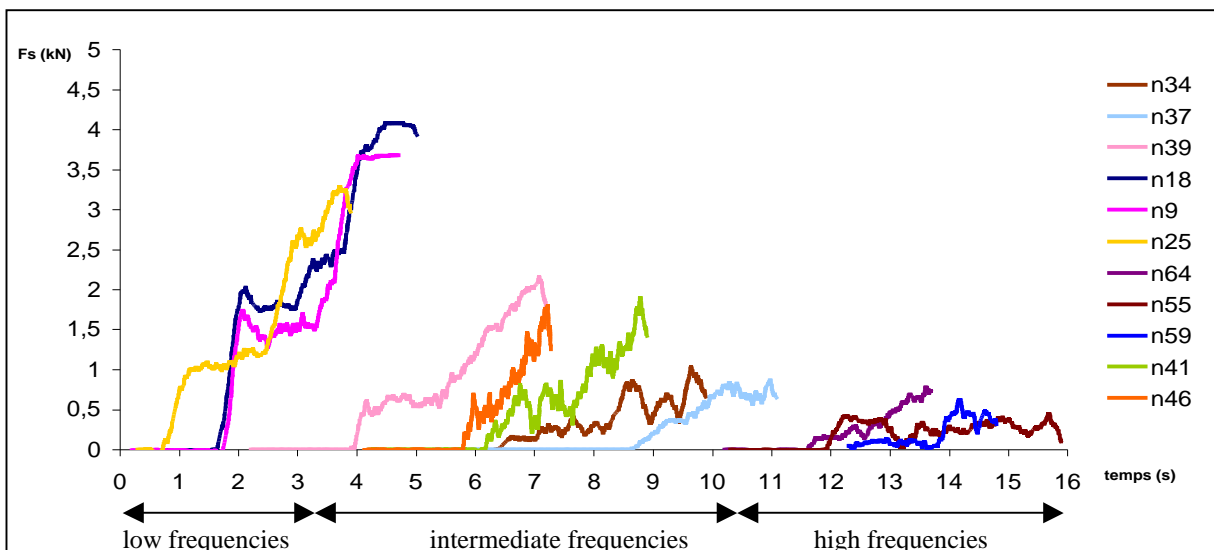


Figure 2 : Tightening force versus the test duration for different ranges of frequencies.

Reference experiments conditions were used to carry out numerical simulations. Simulations make it possible to observe more finely the grain behaviors under vibrations such as convection phenomenon or the formation of vaults (for low frequencies). As in experiments, three different behaviors can be observed according to range of frequencies. This gives a good

qualitative agreement with experiments results: the DE software developed is two-dimensional and experiments are carried out with real grains, comparisons are then limited to qualitative criteria.

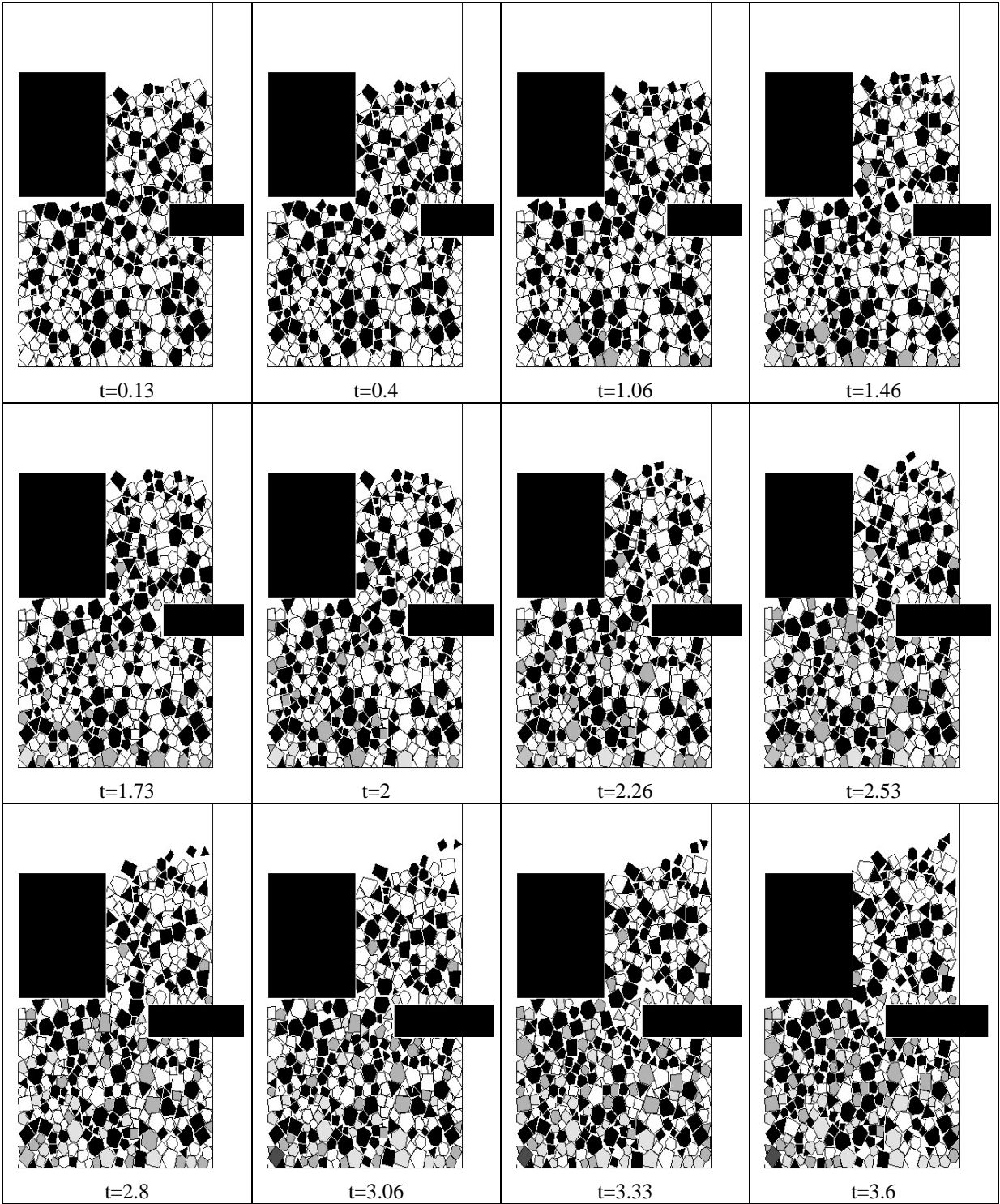


Figure 3 : Numerical simulation of tamping using Molecular Dynamic.

An original reference experiment has been developed. We identify that intermediate frequencies give the best quality of tamping according to the two quality standards defined above. Simulations are in good qualitative agreement with experimental results and allow a finer observation of the phenomenon. This shows the relevance of such an approach and establishes the basis of the comprehension of ballast behavior under vibrations

3 – APPLICATION TO THE PROBLEM OF DEGRADATION OF THE TRACK

A new study has begun using the same principle to study mechanisms that lead to the degradation of the ballast layer. The grains rearrangement are studied, when a great number of cycles of quasi-static loading is applied on a model system, much simpler than real track. In this study, the grains wearing (attrition and damage of points) is not studied. This work is undertaken in collaboration with University of Montpellier and LCPC.

A reference experiment is developed at reduced scale and uses a two-dimensional material: thus, a better quantitative agreement can be expected with two-dimensional numerical simulations. 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 (with three different sizes) to model ballast grains. Rolls are made in cement with sufficient resistance, thus rolls are not damaged during tests. Grains are piled in a case so as to leave free edges as for a transverse section of track. A concrete sleeper is put on rolls. A layer of elastomer is laid on the case bottom to model the under-ballast layer. Cycles of vertical and lateral loading are applied to the sleeper until reaching the structure collapse. This device is currently in construction (see figure 4).

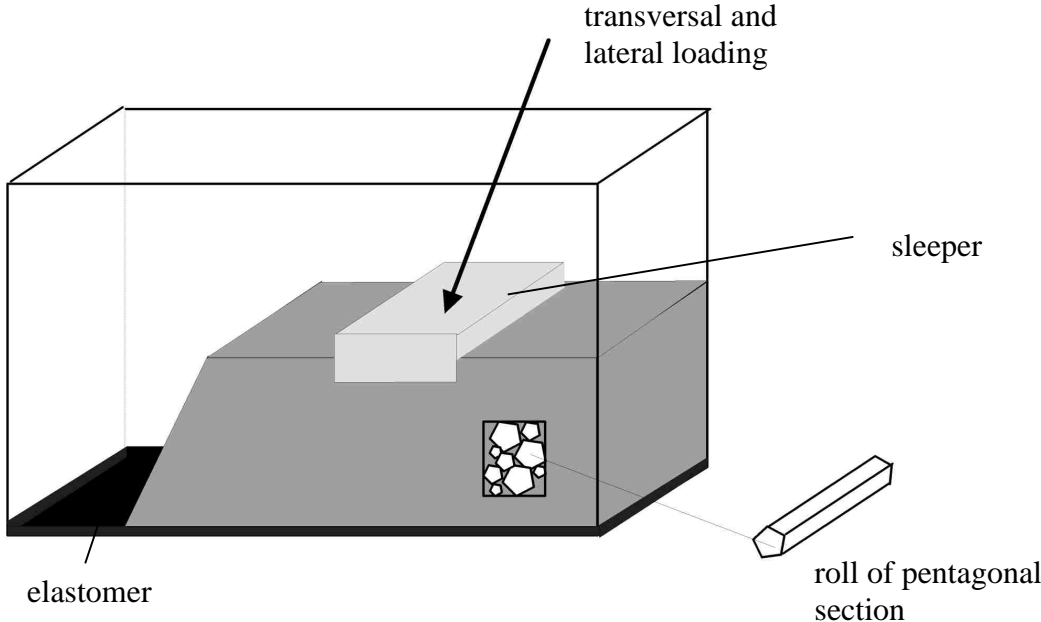


Figure 4 : Reference experiment with pentagonal rolls. A quasi-static vertical and transversal loading is applied until the collapse of the structure.

For numerical simulations, a two-dimensional DE software, Contact Dynamics, developed at University of Montpellier with grains of polygonal form, is used. Contrary as Molecular Dynamic, there is no overlap at the contact points: grains are perfectly rigid. Contact is modeled using an unilateral contact law with dry Coulomb friction. To solve the unilateral constraint problem, efficient numerical methods were developed that use a time increment much larger than in Molecular Dynamics method [4]. Indeed, the main difficulty in these simulations is to carry out a great number of loading cycles: the calculation cost is then important. Another difficulty is to determine the influence of small disturbances (due to error of modeling or errors numerical) 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.

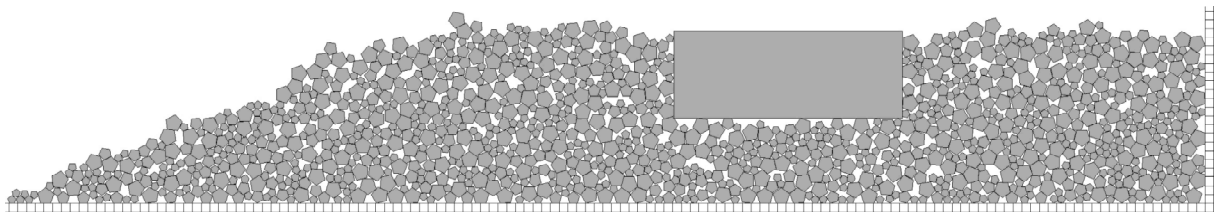


Figure 5 : Construction of the numerical sample using Contact Dynamics.

This study is a preliminary work necessary to determine if DE methods can be applied to calculate evolution of a model granular medium on a great number of loading cycles. It should be then possible to study more complex systems as real track.

CONCLUSION

The studies undertaken showed the relevance of both a numerical and experimental approach using DE methods and reference tests. One in the long term wishes to develop tools, validated on experiments, to understand the mechanisms of ballast. The potential applications are numerous in railway problems as well as in Civil Engineering.

Other studies are also undertaken at SNCF using a continuous approach. In future, we expect to use both DE and FE methods to model infrastructure.

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