PhD opportunity:

Tunnelling in urban areas: improvement of numerical simulations using hollow cylinder tests

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Speciality: Geotechnics et numerical modelling

Context and objectives

The development of public transportation networks is a major challenge for the economic and ecological development of large national and international cities. The density of many urban areas implies the construction of underground infrastructures (tunnels, stations, etc.). For example, the Grand Paris Express project consists in building 200 km of new automatic metro lines around the capital, mainly underground, as well as 68 stations, in sometimes highly urbanized areas.

The construction of shallow tunnels induces movements in the ground and on the surface. These phenomena, if they occur near superficial or deep foundations represent a risk for the integrity of buildings and their level of service (Guilloux & Le Bissonnais, 2016). But, although many research works have studied surface and deep ground movements due to tunnel construction (European project Nettun, FUI project Newtun), predicting the impact of tunnel construction remains a challenge (Yuan & al. 2019).

Since prediction of deformations imposed on structures is relatively poor, the observational method is preferred : in order to limit the risks of foundation disorders, the construction of tunnels is accompanied by monitoring of the buildings and structures along the tunnel route. This makes it possible to adapt the construction method as the work progresses (e.g. parameters for driving the tunnel boring machine) or to take additional measures (e.g. compensation injections).

In particular, the execution of works in a dense urban site implies building in an underground environment already occupied by numerous structures (piles, parking lot, cast walls, other transport network, etc.). This proximity generates interactions and imposes on the neighbouring structures forces and deformations which are not always well understood and cannot be observed as easily as surface displacements. In particular, this project will focus on the effects of tunnel construction on existing deep foundations.

This thesis project is related to the ANR E-Pilot project, one of the objectives of which is to improve the representativeness of numerical simulations of TBM construction by using rheological models that are more suitable than conventional models, on the one hand, and a relevant methodology for the determination of parameters, on the other. We propose in this thesis to develop an advanced constitutive model, particularly adapted to the case of tunneling, taking into account the stress rotation and the anisotropy of natural soils. In order to build and parameterize this new model, we propose to use a high-value laboratory test, the hollow cylinder test, which gives access to parameters of soil behavior that cannot be determined by conventional tests. The wealth of information obtained with this type of test will allow the parameterization and refinement of the rheological models developed.

Proposed work plan

In spite of a sustained research activity and an abundant scientific literature, the prediction of the effects of the passage of the TBM on the surrounding structures remains an open problem: there is not yet a consensus on the numerical procedures to treat this problem and to predict the behavior of the structures.

Bibliographic study

It will allow in particular identifying the state of the art on the following two subjects

- modelling procedures for tunneling with a TBM: the three-dimensional aspect of the problem and the non-linear nature of the interactions between the displacements induced by the TBM and the effects of the displacements on the surrounding area make it necessary to build a complex modelling approach. We will try to propose a generic approach based on a small number of parameters, allowing modelling the effect of the excavation and of the other elements of the construction process (such as the influence of the face pressure for example).

- the choice of an adapted rheological model: one of the possible causes of the lack of accuracy of the numerical simulations is the use of rheological models poorly adapted to the studied problem. In 2021, based on the results of the TULIP project, an exercise to predict the behaviour of piles (open to the geotechnical community), showed the limitations of the models commonly used. The results obtained also showed the interest of models that take into account some anisotropy of natural soils, including the model proposed by Gilleron in 2016.

Improvement of numerical models by use of anisotropic models and hollow cylinder tests

The core of the work focuses on the contribution of the hollow cylinder test for modeling the effects of tunneling.

In a first step, it can be noted that the formulation proposed by Gilleron (2016) was specifically developed to evaluate the surface settlements caused by tunnelling. We will try to modify it, if necessary, to better account for the interaction phenomena with the surrounding structures, in particular the piles. We can also try to make it easier to use.

Besides, the determination of the model parameters remains difficult: Gilleron (2016) only proposed an indirect approach. We propose to investigate this issue further by developing an original laboratory testing program. The triaxial hollow cylinder apparatus allows to characterize the anisotropy of the model, and, on the other hand, to characterize the behavior of the soil according to specific stress paths of the TBM construction. This work will be accompanied by Work Package 1 of the ANR E-pilot project: the tests will be carried out on real soil samples taken from the Grand Paris Express sites. They will be carried out using the Hollow Cylinder Apparatus, which allows the characterization of anisotropy in the three axes as well as the effects of stress rotation (Reiffsteck & al. 2007; Blanc & al., 2011, Symes & al., 1984; Nguyen & al., 2011). The new device that the SRO lab acquired in 2019 also allows for dynamic (5Hz and low-strain) solicitations, thus providing access to characterize the undegraded elastic moduli of the soil.

The last part of the work will consist in updating the formulation of the model implemented in the finite element code CESAR developed by the Gustave Eiffel University, and to test it on three-dimensional configurations.

This thesis work will be based on interactions with the rest of the ANR E-Pilot project (whose program includes centrifuge modeling, experimentation and in-situ instrumentation) and on the results obtained during the TULIP project.

Socio-economic benefits

This project aims to respond to the concerns of contracting authorities such as the Société du Grand Paris (partner in the TULIP project with the Gustave Eiffel University). It proposes an original positioning on modeling methods and a particular test program, which will require the development of procedures and innovative interpretation methods. Nevertheless, it should improve the performance of numerical simulations by using advanced rheological models combined with high value-added laboratory tests.

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