PhD thesis subject 2022-2025

I-Identification of the thesis project

1- Title of the thesis:

Propagation of ground-borne vibrations in complex media in the framework of the excavation phase of tunnels by numerical and analytical methods.

Disciplinary field and speciality: civil engineering

Key words: Wave propagation, transfer function, numerical modelling, in-situ measurement.

Start: October 2022

2- Host structure or laboratory where the doctoral student will be located

LTDS UMR 5513, ENTPE, Rue Maurice Audin, 69518 Vaulx-en-Velin Cedex
GDS Immeuble CAP SUD 106 Avenue Marx Dormoy 92120 MONTROUGE

3- Supervisors

Thesis supervisor: Claude Boutin, Chercheur HDR, LTDS UMR 5513, ENTPE, claude.boutin@entpe.fr, 04.72.04.71.44
Thesis co-supervisors:
Antoine Rallu, Researcher ITPE, LTDS UMR 5513, ENTPE, antoine.rallu@entpe.fr, 04.72.04.70.82
Charisis Chatzigogos, Project Manager Engineer, charisis.chatzigogos@geodynamique.com, 01.46.65.00.11

4- Possible partnership: Centre d'Etudes des Tunnels (CETU), 25, avenue François Mitterrand 69500 BRON

II-Summary of the thesis project

1-Context and objective:

Vibrations generated during the excavation of a tunnel can have an undesirable impact: (i) on structures, (ii) on equipment in structures (measuring devices, medical equipment, etc.), and (iii) on people. The control of vibration annoyance, which may be particularly acute in densely populated areas, constitutes one of the basic design concerns in urban tunnelling. Modelling the wave propagation emitted by a tunnel-boring machine is a complex scientific problem, the understanding of which requires several complementary approaches: (i) in-situ measurements for the definition of input parameters, (ii) theoretical modelling to understand the physical phenomena involved in relatively simple cases (homogeneous elastic soils, simplifying assumptions on the mechanical action of the TBM in situ), (iii) numerical modelling to take into account the complexity of real domains and natural or man-made heterogeneities.

Measurements of the surface vibrations emitted during excavation with earth pressure balanced shield (EPBS) or slurry shields (SS) have already been carried out and presented by several authors, for instance [1,2,3,4]. The presented measurements typically concern maximum surface particle velocities. In these studies, no spectral analysis of the measurements is presented, and there are no measurements close to or on the tunnel boring machines (TBM) or inside the ground. In this context, the ENTPE/LTDS and the CETU carried out different measurement campaigns using systematically a device of synchronous sensors on the surface and on the tunnel boring machine [5]. These measurements will be used in the simulations developed in the framework of this thesis.

Different tasks can be defined pertaining to the three phases of vibration propagation in tunnelling construction: excitation (emission: source characterization) / transfer mobility (propagation in the ground) / immission (propagation within civil engineering structures).

For the phase of emission

- Post-processing and compilation of a database of available measurements from older and ongoing construction sites pertaining to the vibratory excitation levels from tunnel construction with the possibility of enriching the database with ongoing projects during the thesis
- Development of prediction models of vibratory excitation levels for specific configurations of tunnel boring technologies, soil conditions and parameters for the boring procedure (applied pressure at the tunnel front, advancement speed of tunnel etc…)
- Characterization of amplitudes and frequency content for excitation spectra

For the phase of transfer mobility

- Analytical tools for wave propagation within soil media from vibratory excitation due to tunnel boring: such solutions, although they may refer to simplistic geometries are valuable for benchmarking and validating numerical procedures
- Numerical calculations of wave propagation in stratified soil media using a FEM-BEM methodology (2.5D, 3D, Thin Layer Method *etc*)

For the phase of immission

- Study of the interaction between the excavation of the tunnel and the presence of deep foundation elements at the vicinity of the front: risk of damage in the foundations, risk of vibration amplification along the piles (wave guides). Analyses can be undertaken for different types of foundation elements such as: isolated piles, group of piles, caissons and cofferdams (auxiliary structures along the metro line…)

2- Scientific milestones

The main difficulties we will have to face are the following:

- Theoretical formulation and analytical resolution of the dynamic problem with a spread-closed vibration source [6];
- Numerical implementation of the propagation model;
- Dynamic characterization of the TBM;
- Definition and realization of an original in-situ campaign with sensors in the ground.

3- Organization of the thesis:

The present thesis will receive funding from the ANR EPILOT project, and the PhD student will be hosted in Lyon (ENTPE/LTDS) and Paris (GDS).

3.1- Working approach, method, indicative annual programme over the 3 years

- First year:
  - Construction of the numerical model
  - Definition of the experimental protocol
- Second year:
  - Dynamic characterization of the source
  - Carrying out in-situ measurements
  - Exploiting the numerical model
- Third year:
  - Phase of immission

3.2- Necessary resources (data, software, experimental materials, etc.).

Software:

- FEM-BEM: SASSI 2010, MISS3D (Code_ASTER) (FENICS, …)
- FDM: FLAC 3D

3.3- Organisation set up if several directors/supervisors

The supervision is divided between C. Boutin (HdR) [20%, theory], A. Rallu (Dr) [40%, theory, experimental, numerical] and C. Chatzigogos [40%, theory, numerical].

4-References

[1] Hiller, D.M., Bowers, K.H. 1997. Ground borne vibration from mechanized tunnelling works, Proceedings of Tunnelling '97, pp 721-735.

[2] Lunardi G., Macinelli L., Nardone Ch., Panzeri P. 2015. Le vibrazioni nell'ambito dei lavori di scavo mediante TBM. Genrelita e analisi di alcuni casi reali Gallerie e grandi operie sotterranee, n°114.

[3] Bigot A., Farotto G. 2016 - Tunnel boring machine vibration impact prediction method based on surface vibration measurements and tunnel to surface transfer function calculation, 23rd International Congress on Sound & Vibration, Athens, Greece, pp. 1-8.

[4] Grund M., Ritter J.R.R, Gehrig M. 2016. Ground motion relations while TBM drilling in unconsolidated sediments - Rock Mech Rock Eng, 49:1773-1787.

[5] A. Rallu, N. Berthoz, S. Charlemagne, and D. Branque, "In-situ measurements of vibrations induced by TBMs in urban areas", Tunn. Undergr. Sp. Technol., in Press

[6] Pak, R. Y. S. & Bai, X. 2020. Analytic resolution of time-domain half-space Green's functions for internal loads by a displacement potential-Laplace-Hankel-Cagniard transform method - Proc. R. Soc. A Math. Phys. Eng. Sci. 476.