Investigation of unsaturated soil potential liquefaction - effect of suction and density on residual strength

Key words: Unsaturated soils, foundations, Soil liquefaction, Cyclic loadings, Experimental laboratory study, Numerical modeling, Soil structure interaction, Soil stiffness, Soil suction, Risk, Phenomenological law of soil behavior

1- Introduction

The production of renewable energies requires the construction of stable and efficient civil engineering structures. In the case of wind power, tall wind turbines are structures subject to cyclic loading (wind, ocean waves, stop and start effects) on the superstructure and transmitted to the soil via the foundation. Repetitive actions should be addressed by considering cyclic and dynamic effects and the consequences of modifications in soil stiffness, soil liquefaction and continued movement (creep). Regarding the soil liquefaction, this is a phenomenon in which granular soils under cyclic load lose much of their resistance or strength and behave like a liquid. The reason is that loose sands tend to be compacted when subjected to dynamic loading that results in an increase of the pore water pressure and a decrease of the effective stress within the soils. When soils liquefy, the deformation develops rapidly and causes the collapse of infrastructure on a large scale. Recent studies have shown that liquefaction on saturated soil but also on unsaturated soils. However, their behavior has been little studied and poorly understood. Objectives are: (1) Experimental study of the impact of non-saturation on soil liquefaction resistance and residual resistance after liquefaction, (2) Study of suction - liquefaction potential relationships in unsaturated soils, (3) effect of initial stiffness and density (4) Modeling the behavior of wind turbine foundations on unsaturated potentially liquefiable soils.

2- Context of the project

This project focuses on the construction of wind turbines in the littoral zone. The problems of the dimension of the superficial foundations (gravity in off-shore, raft foundation in on-shore) of wind turbines are numerous: bearing capacity and stability of the foundation, degradation of the mechanical properties of the soil under cyclic loading, liquefaction potential, sediment mobility (erosion and accretion), fatigue behavior of soils and influence of unsaturated soil. Furthermore, precisely, this project focuses on the behavior of foundations under dynamic and cyclic loadings, coupling with an experimental approach and numerical modeling.

The collaborative work of the LMN (laboratory of Mechanics of Normandy) located at INSA Rouen Normandy (National Institute of Applied Sciences), LOMC UMR CNRS 6294 (Laboratory of waves and complex media) of University Le Havre Normandy, INCT-Infra, Universidade Federal do Ceará (UFC), Brazil, with the CEREMA (Public Center for Studies and Expertise on Risks, the Environment, Mobility and Development), makes it possible to better understand the behavior of the superstructure and its effects on the soil foundation.

3- Objectives, expected results and main actions

Tall wind turbines correspond to Class 3 structures as defined in Eurocode 7, i.e structures constructed under abnormal soil or loading conditions. These are structures subject to cyclic loading (wind, ocean waves, stop and start effects) on the superstructure, which are transmitted to the soil via the foundation

The interaction between the structure and the soil, results in the need to ensure sufficient bearing capacity to avoid collapse and, mainly, the compatibility of the displacements of the foundation for the well function of the superstructure elements and the equipment (turbines, wings). Repetitive actions should be identified and addressed by considering cyclic and dynamic effects and the consequences of modifications in soil stiffness, soil liquefaction and continued movement (creep).

Regarding the soil liquefaction, this is a phenomenon in which granular soils under cyclic load lose much of their resistance or strength and behave like a liquid. The reason is that loose sands tend to be compacted when subjected to dynamic loading that results in an increase of the pore water pressure and a decrease of the effective stress within the soils. When soils liquefy, the deformation develops rapidly and causes the collapse of infrastructure on a large scale.

Recent studies have shown that liquefaction can be observed not only on saturated soil but also on unsaturated soils. however, their behavior has been little studied and poorly understood.

3-1. Objectives

The objectives of this thesis are:

(1) –Experimental study of the impact of unsaturation on the resistance to liquefaction of the soil and the residual resistance after liquefaction ;

(2) - Study of suction-liquefaction potential relationships in partially saturated soils;

(3)- Study of the role of initial stiffness and density on liquefaction potential and residual strength;

(4)- Numerical simulation of the behavior of unsaturated and potentially liquefiable soils based on an effective stress concept generalized to unsaturated soils.

3-2. Expected results

- Better understanding the liquefaction potential in partly saturated soils: the risk of liquefaction (loss of mechanical strength) of soils due to cyclic loading;
- Effect of cyclic degradation and residual strength on soil structure interactions;
- Role of initial stiffness and density on the evolution of suction in partially saturated soils.

3-3. Main actions

1- Experimental study

Laboratory study of the cyclic behavior of soils and their susceptibility to liquefaction using dynamic triaxaial apparatus instrumented with bender element transducers for stiffness and tensiometer transducers for suction. It involves a cyclic study in the saturated domain to highlight the influence of parameters. Then, more original aspects will be addressed, notably, taking into account the unsaturated soils. In this case, the objective is to study the effect of non-saturation on soil liquefaction resistance and residual resistance after liquefaction. The aim of the two previous steps is to determine the parameters that influence the behavior of these materials. Once the parameters are determined, the elaboration of the behavior law will be carried out.

2- Numerical modeling

Based on laboratory tests, numerical modeling will be carried out using an unsaturated soil behavior law and finite element method on a global scale. This modeling will take into account the effects of degree of saturation, suction and density on soil-structure interactions. The comparison with the laboratory test results, will enable a better understanding of the hydro-mechanical coupling and simulate other boundary conditions of cyclic loadings. Thereafter, modeling of the real-life behavior of the foundations of structures subjected to a field of action defined by the complex behavior of the superstructure in situ using finite element calculation code. This modeling will make it possible to optimize the in-situ instrumentation of the foundations with a view to providing feedback on the long term.