Liquefaction potential of unsaturated soils - application to the wind turbine foundations

Context and general presentation 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 wind turbine 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, with the CEREMA (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.

Objectives, expected results and scientific and technical feasibility of the project

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 movements created by the vibrations and the cyclic and dynamic loads associated with this type of structure cause geotechnical actions, their effects on the soil are currently little known in traditional geotechnics because they are not very common. However, experimental and metrological approaches exist and can contribute to the development of reliable calculation models.

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 sandy soils. however, their behavior has been little studied and poorly understood.

Objectives

1- Impact of non-saturation on soil liquefaction resistance and residual resistance after liquefaction,
2- Study of suction - liquefaction potential relationships in unsaturated soils,
3- Modeling the behavior of wind turbine foundations on near-saturated soils and potentially liquefiable,
4- Taking into account the spatial variability of soil parameters in the formulation of soil behavior laws.

Expected results

- Better understanding the liquefaction potential of a wind turbine foundation: the risk of liquefaction (loss of mechanical strength) of sands or silty sands due to cyclic loads in saturated and unsaturated states.
- Effect of cyclic degradation: some soils are susceptible to undergo a significant degradation of their mechanical properties under the effect of cyclic loadings.
- Effect of cyclic displacements on the superstructure: cyclic loadings cause cyclic and post-cyclic displacements of the foundation and structure and excessive settlement. All these displacements (permanent and cyclic) bring back to the rotor level must remain below tolerances due to the risks of wear and / or fatigue.

Main actions:

1- Experimental study

Laboratory study of the cyclic behavior of soils and their susceptibility to liquefaction. 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 experimentation will be carried out by finite element method on a global scale. 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.