PhD position, 2020-2023
Université Gustave Eiffel, Nantes, France

Subject:	**Study on the liquefaction-induced failure of embankment subjected to earthquakes**
University:	**Université Gustave Eiffel** Since January 1, 2020, Ifsttar has become Gustave Eiffel University! For more information: https://univ-gustave-eiffel.fr
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1 Context

Liquefaction of saturated sandy soils is a phenomenon that occurs under seismic loading. The passage of a seismic wave causes loss of strength and shear stiffness of the soil due to an increase of pore water pressure generated by the cyclic deformations. Liquefaction will result in a sudden loss of stability of structures founded on that type of soil. In the recent years, the lessons of earthquake damages raised around the world, for instance, the 2011 off the Pacific Coast of Tohoku Earthquake damaged many soil-made infrastructures, such as river dikes, road embankments, railway foundations and coastal dikes (Oka et al., 2012). Recently, the seismic hazard of France was recently re-evaluated and new seismic maps were developed (Douglas et al., 2013). Realizing the recent catastrophic earthquake induced damages, it was required that French infrastructures to be implemented with complementary safety standards and new seismic safety margins should be set.

The purpose of the current research work is to have insights on the liquefaction-induced failure mechanism of embankments constructed of looser material (e.g., hydraulic fill) or constructed over younger sediments, since liquefaction is an important concern in these situations. Thus, it can provide technical recommendations that could be helpful for the construction of embankment-type geo-structures in the industrial sector.

2 Objective

Liquefaction-induced failure of earth structures, such as river dikes, levees, road embankments and earth dams, is identified as one of the most devastating consequences of earthquakes. Previous numerical or experimental studies (e.g., centrifuge tests) have shown that the widespread damage to such embankments occurred mainly due to the liquefaction of foundation soil, resulting in excessive settlements, lateral spreading and slope instability. Literatures list possible damaging effects of earthquakes on earth dams and embankments as following:

- Slope failure because of inertial loading and/or softening of materials strength or liquefaction.
- Crest settlement of dam caused by settlement or by earthquake generated water waves in the reservoir.
- Permanent deformation of foundation soils or dam body.
- Sliding failure of an embankment composed of weak or liquefiable soils.
- Piping and erosion

It seems that probably the most important cause of instability of embankment dams is the occurrence of liquefaction during strong ground motions in the loose to medium dense sand and silty sand below the water table and so it should be considered during design procedure of embankments and dams. Due to the presence of embankment dams the sand's cyclic resistance ratio (CRR) is affected by the presence of static shear stresses. Therefore, evaluating the liquefaction resistance of soils with the consideration of the presence of static shear stress is an important step in the engineering design of new structures especially embankment dams and the retrofit of exciting structures in earthquake-prone regions. In this study, the project will focus more specifically on local site effects concerning the onset of liquefaction and the interaction between the foundation soil and the structure.

3 General approach

The main target of this project is to investigate the influence of ground liquefaction on the behavior of homogeneous embankment under seismic loading. Recently, both experimental and numerical studies were carried out on the seismic behavior of embankment taking into account the influence of soil liquefaction (Rapti (2016); Boulanger and Montgomery (2016); Boulanger et al. (2018)). However, several aspects of the embankment on liquefiable ground under seismic loadings are not clarified, which point to a need for additional research to gain experimental insights. The technical strategy of this study will be a combined approach of experimental (70%) and numerical technique (30%). The experimental study will provide important proof on the physical phenomena and essential data for numerical modeling; Being the complimentary of experimental work, the calibrated numerical model is more flexible for providing information and parametric or case studies. The planned steps are the following:

- Centrifuge modeling of liquefaction in free-field condition. This step is to investigate and characteristic the soil liquefaction under difference seismic loadings considering the possible presence of plastic/non-plastic fines. At the same time, provide experimental data to calibrate numerical model. The study of this part will enrich the knowledge on the soil liquefaction behavior and the wave propagation in the liquefiable ground. At the same time, essential experimental experience and techniques will be accumulated and developed which are helpful for the following steps.
- Centrifuge modeling of embankment-foundation interaction considering the influence of liquefaction. Investigate the failure and instability mechanism of the embankment - type geo-structure. Several aspects are focused on in this part. One aspect is the influence of pre-existed static stress on the trigger mechanism of liquefaction under seismic loading; The other aspect is the effect of the deformation and the associated change in stress of the embankments, due to foundation settlement, on the seismic stability of the embankments; Also the importance of post-liquefaction dilative soil behavior in dictating the dynamic response and deformation characteristics of the embankment-foundation system. The experimental data also provide a useful basis for calibrating a numerical analysis and for verifying design guidelines.
- The calibration and verification of numerical simulation will be carried out based on the performed centrifuge test with advanced constitutive model (SANISAND Dafalias and Manzari (2004)) on FEM platform (solid-fluid fully coupled Finite Element (FE) code). The numerical model enables to provide information which is difficult to have in the physical model and helps to reveal the mechanism of failure of embankment under seismic actions. Calibrate numerical model by key experimental data, quantify further the behavior of embankment in liquefied ground with parametric numerical studies.
- Based on the experimental and numerical work, possible remediation strategies could be proposed, which could be helpful for the construction of embankment-type geo-structures in the industrial sector.

4 Working basis and conditions

Working basis and conditions

- Experimental aspect. In this project, the experimental program will be performed in centrifuge team at IFSTTAR (Nantes). The main test facility is the geotechnical centrifuge (200g-ton beam centrifuge with 5.5m of radius) with dynamic shaker (The 1D horizontal shaking table can apply multiple-frequency signals with a maximum acceleration of 0.5g with the mass of the models up to 400 kg). As an important research direction, many experiences were accumulated in the modeling of liquefaction of soil columns and wave propagation problem (Bretschneider et al. (2016)), which are helpful for the future study in this direction.

- Numerical aspect. Parameters of advanced constitutive models have already calibrated by a large database of triaxial tests of sands (Hostun HN31, Fontainebleau NE34). A full solid-fluid coupled soil column model has already been built for liquefaction analysis. This model is a good start and could be extended and developed for the future sophisticated FEM modeling.

5 Candidate profile

Master in geomechanics or geotechnical earthquake engineering; Experience in laboratory tests; Basic knowledge in FEM element modeling; Good level in Matlab/Python and data analysis.

References

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