CERIS : Civil Engineering Research and Innovation for Sustainability

Liquefaction mitigation measures: prospective application to immersed tunnel foundations

PhD student
Luís Carlos Rodrigues de Sousa Miranda

PhD program
Civil Engineering (IST, University of Lisbon)

Supervisor
Laura Caldeira (LNEC)

Co-supervisors
Rui Carrilho Gomes (CERIS, IST, University of Lisbon) and João Bilé Serra (LNEC)

Period
2014-2019

Funding
FCT scholarship (SFRH/BD/99581/2014)

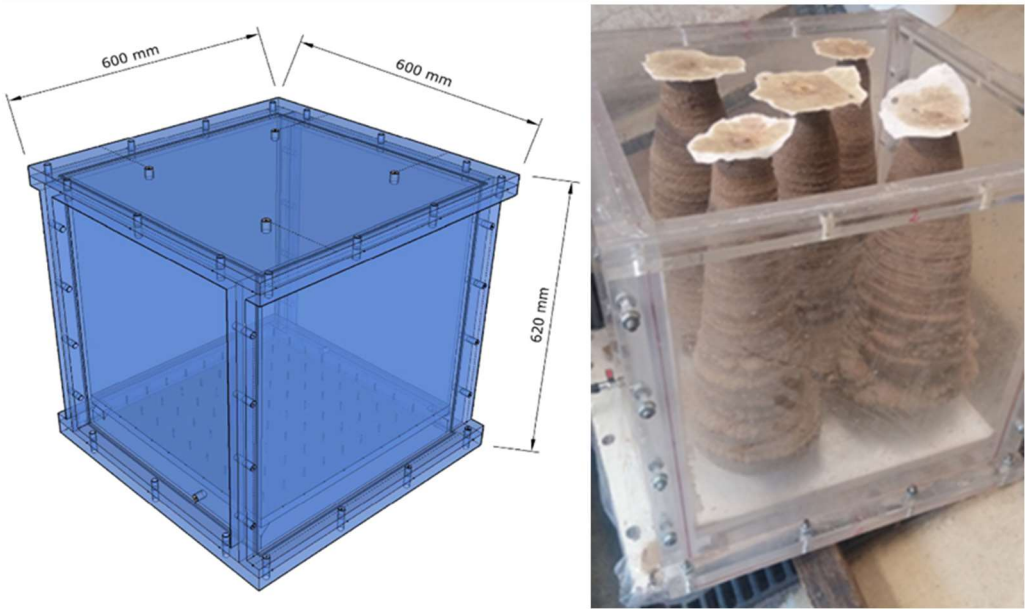
Summary

A state-of-the-art revision of immersed tunnels is done. The selected case-study for this thesis, an immersed tunnel for crossing Tagus River between Algés and Trafaria, is presented. Next, cases of earthquake-induced liquefaction and its associated mechanism are discussed. The most relevant constitutive models for the numerical simulation of the response of soils under cyclic loading are described, including the Manzari-Dafalias model. Subsequently, Tagus River sand is physically characterized and six monotonic drained triaxial tests are analysed, with the goal of characterizing the stress-strain behaviour of the sand and obtain its parameters. Five cyclic undrained torsional tests are also analysed with the goal of characterizing cyclic behaviour of the sand. Then, the calibration framework for the Manzari-Dafalias model is presented, combining results of laboratory tests with numerical sensitivity studies. A parameter sensitivity analysis is carried out to understand the relevance of some chosen model parameters, by using an OpenSees constitutive driver, both through numerical simulation of monotonic drained triaxial tests and of cyclic undrained torsional tests. Some model parameters are calibrated directly from triaxial testing. The remaining parameters are calibrated through numerical simulation and curve fitting of the model to the laboratory results.

A new constitutive driver is implemented in MATLAB to clarify some of the Manzari-Dafalias model issues, namely in the liquefaction phase. Finally, multiple liquefaction mitigation measures, and their application in immersed tunnels, are described. Laboratory testing of a mitigation measure, specifically injection of a duromeric expansive polyurethane resin, commercially available, is accomplished. The physical characteristics of both the resin and of the sand-resin mixture are presented. A series of tests, namely high frequency ultrasonic pulse tests, uniaxial compression and tensile tests, and triaxial compression tests, are performed. The modulus of elasticity, the Poisson's ratio, the uniaxial compressive and tensile strengths, the triaxial compressive strength and the shear strength parameters, are determined. Two additional injection tests are executed to check densification of the sand between injection columns and its relative density is determined. Finally, the main conclusions are summarized and guidelines for future developments are established.

Keywords

Immersed tunnels, liquefaction, advanced laboratory testing, numerical modelling, Tagus River sand – expansive polyurethane resin mixture.



Sand box design (left) and columns of sand-resin mixture after injection (right).