Fifth Lecture by

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ETH Zurich, Switzerland

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Vulnerability Assessment and Retrofit of Existing Bridge Foundations

Abstract

The vast majority of existing bridges were built before the 90's, without any or just basic seismic design. Pile group strengthening can be a challenging, costly, and time-consuming operation, calling for optimised solutions. The lecture will look into the behaviour of pile groups under combined Vertical, Horizontal and Moment (VHM) loading, combining 3D Finite Element (FE) and centrifuge modelling. Initially, a proof-of-concept study is conducted, inspired by the recent widening of a Swiss bridge. According to conventional design, the existing pile group needs retrofit to accommodate the increased seismic loads due to widening. An unconventional "do-nothing" approach is explored (maintaining the existing foundation), exploiting nonlinear soil response. Such an approach requires improved design methods and better definition of the ultimate capacity of pile groups under combined loading. In this context, after developing a database of Swiss bridges and identifying pile group typologies encountered in practice, a fundamental yet representative 2 x 1 bored pile group is tested at the ETH Zurich (ETHZ) Geotechnical Centrifuge Centre (GCC). Four experimental setups are developed and verified for vertical, pushover, combined, and vibration testing. After determining the bearing capacity under vertical loading, pushover loading is employed to measure the moment capacity (M_{ult}) of a lightly- and a heavily-loaded (widening) pile group. In contrast to intuitive expectations, the heavily-loaded system mobilises larger M_{ult}. Combined loading is performed to derive experimental failure envelopes, confirming their tendency to expand with increasing vertical load. The centrifugulte results are used for FE model validation. The numerical technique is upgraded to account for nonlinear soil–pile interaction, using hypoplasticity for sand and appropriate modelling of interfaces and pile response. The transition to prototype scale accounts for scale effects, and employs the Concrete Damaged Plasticity (CDP) model for proper simulation of the reinforced concrete (RC) piles. The latter is a key advancement, accounting for the axial load dependency of bending moment capacity. The problem is studied parametrically, deriving failure envelopes in function of vertical loading, confirming the increases of pile group capacity with increasing vertical load. Finally, the Limit Equilibrium method is used to derive closed-form analytical failure envelopes, providing a useful design tool for engineering practice. The latter are verified against the FE analysis results.

About the Speaker

Ioannis Anastasopoulos has been Full Professor and Chair of Geotechnical Engineering at ETH Zurich since 2016. He specializes in geotechnical earthquake engineering and soil–structure interaction, combining numerical with experimental methods. His academic degrees include a PhD from the National Technical University of Athens (NTUA), an MSc from Purdue University, and a Civil Engineering Diploma from NTUA. His research interests include resilient seismic design and preparedness, innovative seismic hazard mitigation techniques, sustainable retrofit of bridge foundations, improved methods for sustainable geotechnical construction, faulting and its effects on infrastructure, site effects and slope stabilization, foundations for renewable energy, tsunamis and their effects on coastal infrastructure, scouring of bridge foundations, soil liquefaction and structure–soil–structure interaction. He is the inaugural recipient of the Young Researcher Award of the ISSMGE in Geotechnical Earthquake Engineering, and the winner of the 2012 Shamsher Prakash Research Award. He has been involved as a consultant in a variety of projects of significance in Europe, but also in the US and the Middle East. His consulting work ranges from the design of pile-rafts of tall buildings/towers, special seismic design for new and retrofit of existing bridges, retaining walls, metro stations and tunnels, to harbour quay walls, and special design against faulting–induced deformation. He is National Delegate-Expert for Switzerland for the 2nd generation of Eurocode 7 and member of the SIA 267 Commission on Geotechnical Design. Moreover, he is actively engaged in the organization of international conferences (e.g., ICONHIC), specialized workshops and training courses, fostering knowledge transfer and fruitful interactions between the academia and the industry. He currently serves as Associate Editor of Soil Dynamics and Earthquake Engineering, Journal of Earthquake Engineering, and Frontiers in Built Environment, and has served as EBM of Géotechnique and of the ICE Geotechnical Engineering Journal. As of 2021, he is a member of the Board of Directors of the International Association for Earthquake Engineering (IAEE).