Research Project Highlight

Ground Improvement-Based Protection of Transportation Infrastructure: Validation of PBE via Centrifuge and Numerical Modeling

TSRP Topic – Evaluate New Systems, PBE – S2

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Start-End Dates:
2/1/2020-1/31/2022

Abstract
This study builds upon previous research illuminating the propensity of rocking footings to dissipate energy into the ground and re-center themselves during and following an earthquake – thereby protecting the superstructure from sustaining undue damage. Essentially, to induce rocking the footing must be under-designed, that is, sized smaller with a lower safety factor against bearing failure. However, a consequence of allowing the footing to rock is that it may exhibit undesirable deformations, including large transient rotations and residual settlements during and following shaking, respectively. Strategically designed ground improvement beneath the foundation can control such detrimental kinematics. To refine the best ground improvement strategies, a numerical model in the OpenSees platform (detail of the model shown in *Project Image B*) was assembled and validated against centrifuge experiments conducted at UC Davis. Next the numerical model will be used to design our own centrifuge test program in the coming months.

This testing program is geared around resolving unanswered questions, including the appropriate balance between enhanced energy dissipation and acceptable residual settlement, and the level of ground improvement needed to reach that balance. After corresponding with practicing engineers (including James Gingery and Lisheng Shao) the primary ground improvement method to be tested is soil-cement columns owing to their prevalence in local practice. A relatively heavily loaded footing will undergo shaking with and without the improvement in sand samples carefully curated with an air pluviator designed to fill a flexible laminar container, to be mounted on the centrifuge's shaking table. The laminar container (*Project Image A*) has been assembled with instrumentation needed to monitor its orientation during shaking. The footing is loaded with a static mass (rather than a load actuator) for

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simplicity and to ensure constant vertical load during shaking. While the numerical model is complete, centrifuge tests are expected to begin by April of 2021.

Deliverables
An overview of typical rocking shallow foundation characteristics and the rationale for that chosen for this project has been prepared (Deliverable M1). An OpenSees numerical model has been developed and validated against experimental data in the literature (Deliverable M3); this is the subject of an upcoming conference paper, and following the centrifuge testing, will be expanded to compare to the present programs test results. Centrifuge testing has been delayed due to the pandemic, and subsequent repairs required to the equipment (Deliverable M2), however a model footing and instrumentation apparatus have been constructed. The centrifuge testing is expected to yield papers and the project will provide the basis for a Ph.D. thesis as well. Specific deliverables and an updated timeline (as of March 2021) for each are described below.

M1. February – May 2020: develop a suite of archetype bridge and rail support bent-shallow foundation components using design and construction plans of bridge and rail systems collected from practitioners. This work will form an important contribution to the baseline for test specimen design and modeling, and it will form a portion of the final report for the project.
M2. June 2020 – April+(TBD) 2021: design, construct and test two suites of centrifuge shake table experiments with approximately 4-6 model footings within each soil container. Both unimproved and improved soil specimens will be tested within similar containers to allow direct cross-comparison. Note that the testing time frame is TBD, pending repairs to UCSD centrifuge. The specimens have been designed, however test execution is pending centrifuge repair progress.
M3. +April – August 2021: develop numerical models of the experimental specimens using OpenSees and cross-compare numerical simulation response results with experimental measurements
M4. September - February 2022: expansion of numerical analyses considering a wide range of soil, foundation, and ground improvement types and execution of a PBEE analysis to evaluate the cost implications (and compare with the benefits) for ground improved transportation structures.

Research Impact
By developing a strategy to control the detrimental kinematics of plastic hinging foundations, practice can move and embrace a natural, cost-effective solution with its implementation in PBE of transportation infrastructure. The proposed approach, via implementation of ground improvement strategies below rocking foundations, supports use of readily accepted concepts in geotechnical practice. We anticipate these concepts will be readily accepted in practice with sufficient experimental and numerical evidence. It is noted that the use of ground improvement strategies is also readily extensible

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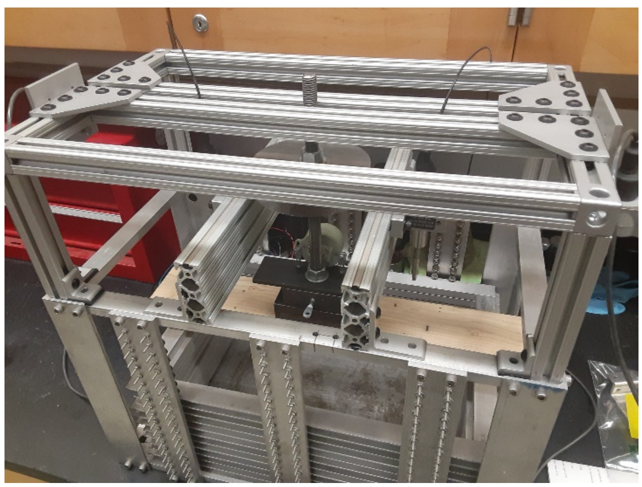
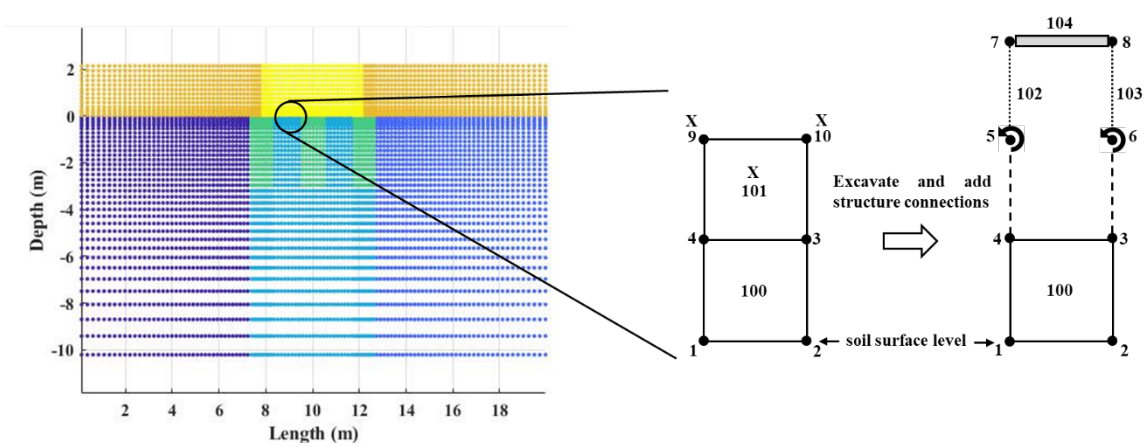
to retrofit design and thus when the additional rocking and/or energy dissipative benefits of an existing transportation structure foundation support system are needed to enhance seismic performance, coupling with ground improvement to control deformations offers a feasible option. Ultimately, adaption of this concept will reduce risk to infrastructure in the event of severe earthquakes, limiting potential service disruptions and costly repairs to transportation systems.

Project Images



A) Centrifuge-ready model footing with instruments mounted on laminar container



B) Depiction of OpenSees model, detail of rocking connection at right