DYNAMIC SOIL-STRUCTURE INTERACTION IN BUILDINGS WITH OIL DAMPERS

Jad I. Boksmati

Department of Engineering
University of Cambridge

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Research into the seismic performance of structures with oil dampers have so far been driven primarily by the structural engineering community, with influential experimental work on the topic originating mainly from large scale shaking table testing of fixed-base prototype frames. Despite considerable advancements over the years in building complexity and realism into these test structures, little to no experimental effort has been made to investigate dynamic soil-structure interaction in such structures. Fixed-base shaking table testing of structures fitted with oil dampers confines energy dissipation to the supplemental damping devices alone, neglecting any contributions from foundation-soil inertial interaction that may arise in the field. A considerable portion of literature on oil dampers in structures emanates from a mathematical optimisation background, proposing computational algorithms to solve for optimal damper sizes and locations in a structure. Such iterative linear analysis is conducted in the frequency domain, and offers limited physical insight into the different facets of this complex nonlinear Soil-Structure Interaction (SSI) problem. Numerical and analytical work examining the effects of SSI on buildings with oil dampers have been limited in nature, often resorting to equivalent linear procedures to simplify the modelling of geometric and soil nonlinearities at the foundation-soil interface. This research seeks to address some of these limitations by pioneering the application of high gravity geotechnical centrifuge testing as a viable research tool to experimentally investigate dynamic SSI in buildings with oil dampers.

Miniature oil dampers for use in small-scale model structures were developed for this purpose, following a series of trial-and-error experimentations. Sixteen centrifuge tests were conducted in total, each involving two similar 2-DOF linear elastic structures, one fitted with miniature oil dampers, and one left bare for comparison. Ground flexibility was varied between tests by changing frame base fixity conditions from fully rigid fixed base, to shallow embedment of raft foundations into dry dense and loose sand beds. Aspect ratios and foundation bearing pressures of the model structures were also varied to trigger different levels of SSI. Miniature accelerometers were used during the centrifuge tests to measure soil and structural accelerations, along with miniature load cells to track experimental oil damper hysteresis during shaking. The model frames were subjected to near resonant frequency sinusoidal excitations of different magnitudes to trigger different levels of SSI. The dynamic response of the structures to realistic multi-frequency component excitations was also recorded.

Inter-storey oil dampers as tested in this study have delivered consistent improvements to the seismic response of structures for all of the input motions and ground conditions investigated in the centrifuge. It was found that additional viscous damping in the superstructure came at the expense of inertial interaction at its foundation-soil interface. The damped soil-structure systems were less sensitive to changes in ground conditions and foundation bearing pressures compared to their regular bare frame counterparts. Optimal oil damper control over structural accelerations and drifts was recorded for fixed base conditions, during weak excitations that did not trigger considerable resonance in the superstructures. Upon shallow embedment of the rafts into dry sand beds, reductions in damper control were reported, reaching minimal levels for the loose sand cases during moderate to strong near resonant frequency excitations. These reductions were not the result of subpar performance of the damped structures per se, but rather a consequence of the considerable improvement in the dynamic response of the regular frames being used as comparative benchmarks. If the foundation of a regular structure is permitted to rock during strong shaking, experimental evidence points to dynamic responses that are close to those expected from a similar structure fitted with oil dampers. However, such natural seismic mitigation measure was shown to be highly variable and unreliable for weaker excitations.

Base flexibility and dynamic SSI did not have adverse consequences on the performance of structures fitted with oil dampers. While it is true that reductions in oil damper hysteresis were observed with reducing base fixity, this should not be interpreted as degradation in damper effectiveness. On the contrary, when excited close to resonance, the damped frames exhibited similar, albeit slightly lower, floor accelerations as base fixity was reduced. Estimation of the seismic input energy into a soil-structure system during near resonant frequency shaking showed both, damped and bare structures benefiting from natural rocking isolation; releasing the foundation rotational kinematic restraints lowers total energy going into the superstructures, causing the oil dampers in the frames to do less work. Even during SSI, the oil dampers continued to be the primary source of energy dissipation in the soil-structure systems.

Lastly, the promising application of using nonlinear lumped-parameter structural models, with hyperbolic foundation moment-rotation backbone curves to predict centrifuge data, was demonstrated for the damped and regular bare structures. Such simplified models, solved in the time domain, offer a more elegant solution during early stage design compared to the response spectrum procedures currently advocated by published guidelines on the analysis of damped structures.