Geotechnical Seismic Simulation Using OpenSees

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Introduction

The PEER analytical platform OpenSees has been developed to combine advanced structural and geotechnical seismic simulation capabilities. A number of advanced soil constitutive models are developed and implemented in OpenSees, covering a range of sand and clay cyclic response characteristics. Effort has been made to calibrate these models, and incorporate in simulations of large structure-soil systems using OpenSees. Herein, calibration, implementation, and use of a liquefaction sand model is presented and discussed.

Applicability

The developed sand constitutive model is three-dimensional, and is based on multi-surface plasticity (Figure 1). This model is capable of simulating: 1) pressure dependence of sand stiffness and shear strength, 2) dependence of pore water pressure on shear loading, and 3) large post-liquefaction cyclic shear strain accumulation. The latter is directly related to assessment of lateral spreading in liquefied sands, which is one of the most important damage measures for liquefiable soil sites (see Yang 2000 for more details). This constitutive model may be embedded in one of the existing 2D or 3D solid elements available in the PEER OpenSees platform (McKenna and Fenves 2001), in order to conduct seismic simulations of soil-structure systems. In OpenSees, sets of model parameters are available to simulate medium to dense sand response. These parameters were calibrated based on

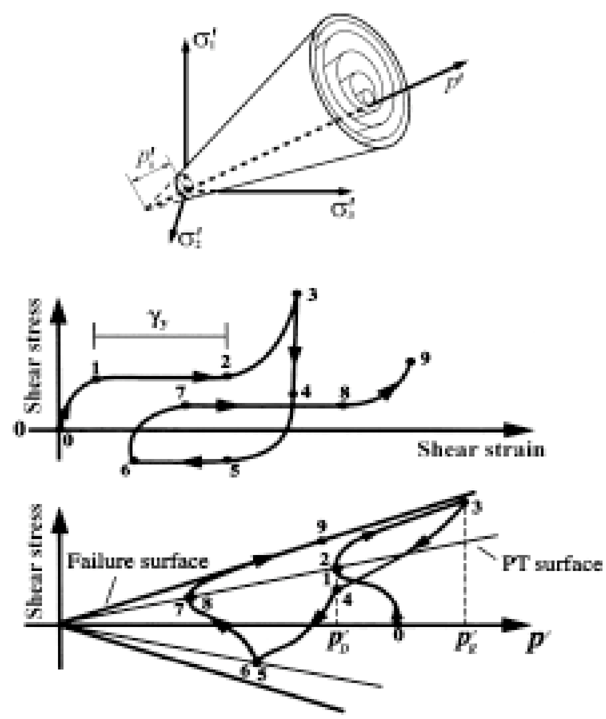

Figure 1 – Yield surfaces and undrained performance of the sand model

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existing experimental data (e.g., Arulmoli et al. 1992, Kammerer et al. 2000), along with engineering judgement.

Model Calibration

As an example, model calibration was conducted for dense Nevada Sand (at a relative density of about 90%), based on experimental results from three stress-controlled undrained cyclic shear tests conducted using the UC Berkeley bi-directional simple shear device (see Kammerer et al. 2000 for detailed description of the experimental program). These three tests (NS8, NS11, and NS12) varied in initial vertical effective confining pressure (96 kPa, 44 kPa, and 36 kPa), cyclic stress ratio (CSR = 0.26, 0.22, and 0.53), and the amplitude of static stress bias ($K_{\square}$ = 0.0, 0.08, and 0.09). A single set of model parameters was calibrated to simulate all three tests (Figure 2 shows NS11 results).

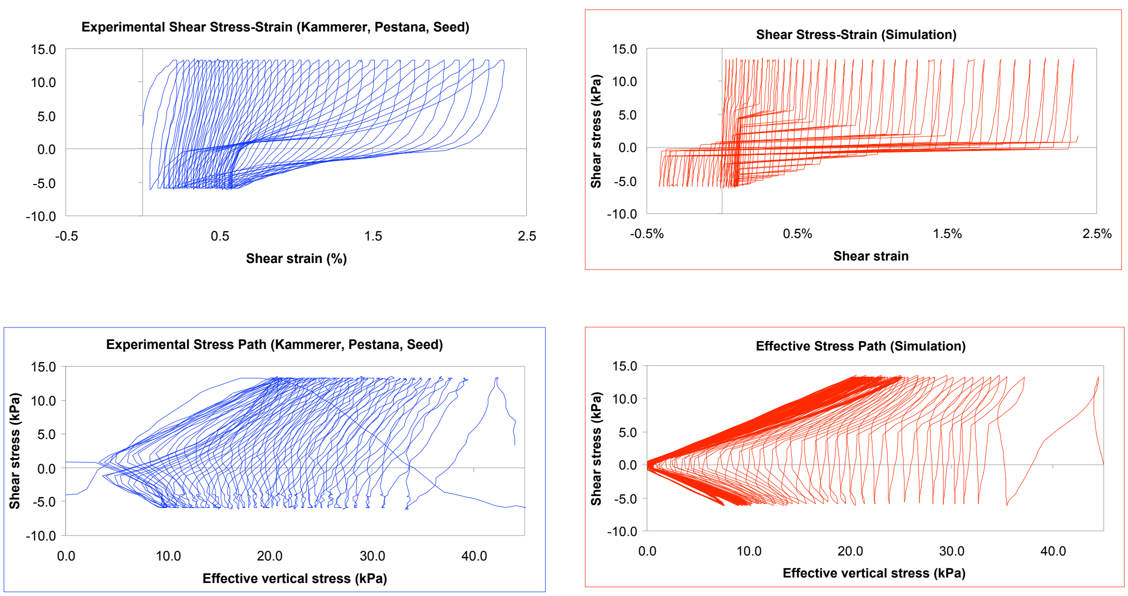

Figure 2 – NS 11 experimental (left, Kammerer et al. 2000) and computed (right) response of dense Nevada sand.

Application within OpenSees

An ongoing research effort within PEER employs OpenSees to investigate the seismic performance of an actual bridge site, the Humboldt Bay, Middle Channel Bridge (Figure 3). A two-dimensional analytical model of this bridge, including the superstructure, piers, foundation piles, and supporting soil, is being carefully studied. Herein, some preliminary simulation results from this study are presented.

The Middle Channel Bridge is located at Eureka, northern California. The river channel has an average slope from the banks to the center of about 7% (4 degrees). The foundation soil is composed of mainly dense fine-to-medium sand and organic silt and/or stiff clay layers. In addition, thin layers of loose sand and soft clay were also seen near ground surface. The bridge piers are supported on 8 pile groups, each of which consists of 5 to 16 prestressed concrete piles.

A 4-node quadrilateral element is used to discretize the soil domain. The soil below the water table is modeled as an undrained material, and the soil above as dry. The above-described liquefaction constitutive model was employed for sands and silts. A near-field strong motion record (PGA=0.8 g) was applied to the model base. Figure 3 shows the deformed mesh after the shaking event. A main characteristic in this figure is that the abutments and riverbanks moved towards the center of the river channel (lateral spreading mechanism). This is a direct consequence of the reduction in soil strength due to pore-pressure buildup. This pattern of deformation may be typical of many practical situations, and should receive attention in design and/or retrofitting assessments.

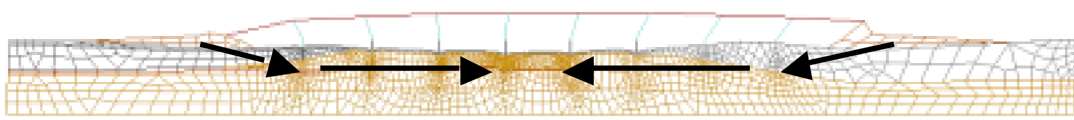

Figure 3 – Final deformed bridge site model (joint work with Prof. Joel Conte and Mr. Yuyi Zhang at UCSD).

For further information

Interested OpenSees users are encouraged to contact the authors with questions specific to their geotechnical applications. Inquiries may be sent by email to A. Elgamal (elgamal@ucsd.edu), or to Z. Yang (zhyang@ucsd.edu).

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Keywords
OpenSees, liquefaction, constitutive model, lateral spreading.