

2015 SCEC Workshop on Soil-Structure Interaction of Complex Systems

Organizers: Jacobo Bielak (CMU), C.B. Crouse (AECOM), Tom Jordan (SCEC/USC)

Date: Thursday, January 29, 2015 (08:00-15:30)

Location: University of Southern California, Los Angeles, CA

Participants: 24 (by invitation only)

Objective

The project objective was to organize a one-day workshop to discuss current issues associated with the simulation of soil-structure interaction (SSI) of complex building and non-building systems during strong earthquakes, and to identify research needs and areas of application in which SCEC research might contribute to addressing those needs. The workshop took place on January 29, 2015 in Los Angeles at the University of Southern California, with 24 invited participants from industry, government, and academia. The workshop was divided into four sessions. Initially, several speakers gave short presentations on the current state-of-practice and needs for SSI effects in different types of infrastructure systems, including building structures, foundations, multi-structure systems, nuclear power plants, and dams and related geotechnical engineering structures. This was followed by a session on methods of analysis for SSI and related software. Third was a presentation on SCEC activities related to engineering applications. The fourth, an entire afternoon, session was devoted to a discussion of needs and desirable actions and developments. Prior to the workshop, the organizers sent to the participants, along with the agenda and list of participants, an overview of the workshop to help shape the presentations and discussions. The overview, agenda, and list of participants are given below. In addition, some of the presentations are available on-line at the SCEC website SCECpedia (http://scec.usc.edu/scecpedia/2015_SCEC_SSI_Workshop)

Agenda

08:00 - 08:30 Welcome Breakfast

08:30 - 08:45 Introductory remarks and meeting agenda - Jacobo Bielak

09:00 - 10:30 Current state-of-practice and needs for SSI effects in:

(Greg Deierlein, moderator; Justin Coleman, reporter)

* Foundation-soil interactions - Jonathan Stewart

* Building structures - Robert Pekelnicky

* Buildings and infrastructure systems - Ibrahim Almufti

* Nuclear power container structures - Enrique Luco

* SSI Analysis with Soil Modeled as a Continuum - Ethan Dawson

10:30 - 11:00 Discussion

11:00 - 12:00 Methods of analysis and related software

(Domniki Asimaki, moderator; Ethan Dawson, reporter)

* SASSI - Farhang Ostadang

* LLNL software - Jerome Solberg

* Nonlinear analysis Justin Coleman

12:00 – 12:30 SCEC activities related to engineering applications - Tom Jordan

12:30 - 13:15 Lunch

13:15 - 15:30 Discussion of needs and desirable actions and developments
(C.B. Crouse, moderator; Sanaz Rezaeian, reporter)

15:30 Adjourn

Overview

The evaluation of SSI effects during earthquakes is currently conducted, by and large, using variations of methods based on highly simplifying assumptions that were developed originally over fifty years ago. For instance, the current SSI provisions in the ASCE 7-10 standard are based on simplified analytical methods developed in the 1970s. Minor improvements have been made since then, and revisions to the SSI provisions in the forthcoming ASCE 7-16 standard were made in the current code cycle. These revisions, however, are still based on the same simplified equivalent linear model on which the original recommendations were based.

Structural engineers typically use commercial software for dynamic analyses that can model the 3-D geometry and stress-strain characteristics of the structure in great detail, but these software programs model the SSI effects crudely, if at all. Similarly, geotechnical engineers use commercial software that can model the complex constitutive behavior of the soil, but these software programs cannot accommodate complex 3-D structural models. Another potentially important factor is the spatial variability of ground motion and how to model it in complex geologic media; this problem is especially important for elongated structures such as dams and bridges, and for other complex multistructural systems such as nuclear power plants. With the increased attention being paid to the nation's infrastructure, it is now an appropriate time to bring together seismologists and engineers to (a) assess current practice in SSI and related recent methodologies, and (b) examine unmet needs and potential methodologies for addressing such needs.

Participants

Ibrahim Almufti (Arup)
Domniki Asimaki (Caltech)
Mohsen Beikae (Metropolitan Water District of SoCal)
Jacobo Bielak (CMU)
Justin Coleman (Idaho National Lab)
C.B. Crouse (AECOM)
Ethan Dawson (AECOM)
Greg Deierlein (Stanford)
Asa Hadjian (Defense Nuclear Facilities Safety Board)
Ben Husmand (Hushmand Assoc)
Tran Huynh (SCEC/USC)
Tom Jordan (SCEC/USC)
Dennis LaChaine (Metropolitan Water District of SoCal)
Enrique Luco (UCSD)
Nico Luco (USGS)
Phil Maechling (SCEC/USC)
Mike Mehrain (AECOM)
Farzad Naeim (Farzad Naeim, Inc.)
Farhang Ostadan (Bechtel)
Robert Pekelnicky (Degenkolb Engineers)
Sanaz Rezaeian (USGS)

Wolfgang Roth (AECOM)
Jerome M. Solberg (LLNL)
Jonathan P. Stewart (UCLA)

Summary

An early observation made by several speakers was that most seismic provisions for incorporating soil-structure interaction effects in building codes, as well as for the seismic design of nuclear power plants, are based on methodologies developed over 30 years ago. There have been recent efforts to update the early work and to answer the question of when the effects of SSI are significant. One such effort was the NIST-sponsored research conducted under the NEHRP Consultants Joint Venture, a partnership of ATC and CUREE. This research resulted in the 2012 NIST report, Soil-Structure Interaction for Building Structures (NIST GCR 12-917-21), which was used to update the SSI provisions in Chapter 19 of the forthcoming ASCE 7-16 standard.

Some highlights of the first session are:

- It is often assumed that SSI effects are always beneficial. It is now well known that this is not necessarily the case. Thus, it is important not to assume that ignoring SSI is conservative.
- SSI effects are significant for cases in which the height of the structure divided by the product of the fixed-base fundamental natural period of the structure times the shear wave velocity of the soil around the structure is greater than 0.1.
- The spatial distribution of the ground motion is usually not considered in the analysis and there is concern about the procedures currently used to evaluate the reduction in ground motion that occurs at higher frequencies due to the filtering effects from the embedment of the foundation and the base slab averaging. Current procedures for evaluating the effective ground motion at the base of the structure can result in reductions that are as large as 80 percent of that in the free field.
- SSI effects in nuclear power plants (NPP), which are stiff and massive structures, can be significant when they are embedded in soil. Structural behavior is currently assumed to remain linear. High frequencies are a concern because of the equipment. There is an increase in torsional and rocking response with inclined waves; oftentimes incident motion is taken as consisting only of vertically incident waves.
- More advanced nonlinear analyses for modeling SSI effects are already being used by industry. From a geotechnical perspective several applications (e.g., dams, retaining walls, pile foundations) were illustrated in which FLAC, a geotechnical and rock mechanics software package, was used for the analysis. This code is capable of modeling nonlinear soil behavior, including slip and separation. However, for pile foundations, nonlinear springs (p-y, t-z, and Q-z curves), developed in the 1970s from static or slow cyclic tests on prototype piles are still typically used to model the interaction between individual piles and adjacent soil.
- Another issue is the question of how the design spectrum is modified due to gapping and sliding at the interface between the soil and the structural foundation.

- Another major practical application described at the workshop dealt with the New Transbay Transit Center (TTC) in San Francisco. This is a major urban development with many stakeholders concerned about interactions between their properties. It represents an important example of SSI and Structure-Soil-Structure Interaction (SSSI) in a highly seismic zone. It entailed the development of bedrock ground motion (assumed to be spatially uniform), nonlinear site response analysis, kinematic effects on deep basements, prediction of excavation-induced movements of adjacent existing buildings, quantifying static and seismic load-paths between soils, piles and adjacent basements for structural design, and assuring that new towers being erected in the vicinity do not invalidate the earthquake performance requirements of the TTC. The advanced numerical simulations were conducted using LS-DYNA, a commercial finite element tool capable of modeling non-uniform 3D non-linear response of the soil domain and the construction sequence followed by earthquake response. Because of the importance of the project, a major construction monitoring instrumentation system was installed. Gaining access to the recorded data would be highly valuable for future validation studies.

The second session was devoted to a description of several additional advanced software tools currently used or under development for the analysis of complex SSI and SSSI applications, primarily associated with the nuclear industry.

- The first one, SASSI, is the industry-standard tool used today for the SSI analysis of nuclear power plants. It is a commercial finite element code in the frequency domain that represents the soil as a horizontally layered anelastic model and simulates inelastic soil behavior by adjusting the shear modulus and intrinsic damping as a function of the local shear strains. The incident wave is most often idealized as a vertically incident shear wave polarized in the horizontal direction (SH or SV). A variety of elements are available to represent the foundation and superstructure.
- Another tool discussed during the workshop is a generalized time-domain method for Soil-Structure Interaction Analysis based upon an extension of the Domain Reduction Method for incorporating arbitrary incoming ground motion. The LLNL-developed modified method has been implemented in LLNL's nonlinear time-domain structural mechanics code, DIABLO. The methodology has been combined with the use of a simple hysteretic soil model based upon the Ramberg-Osgood formulation and applied to a notional Small Modular Reactor. These benchmark results compare well with those obtained by using SASSI. The methodology provides a new alternative approach for the investigation of other sources of nonlinearity, including those associated with the use of more physically-realistic material models incorporating pore-pressure effects, gap opening/closing, the effect of nonlinear structural elements, and 3D seismic inputs.
- A third presentation addressed the current status of non-linear analysis of SSI (NLSSI) in the nuclear industry. Present barriers to conducting nonlinear analyses in practice are the lack of acceptance of nonlinear behavior in ASCE-4; perceived (or real) limitations of time domain software to perform NLSSI; lack of a general NLSSI methodology: INL has developed such a methodology. The soon to be released ASCE 4-15 has a non-mandatory appendix that will allow nonlinear time domain SSI analysis. The short to medium range is to provide the DOE and Industry with robust analytical methods for evaluating a range of seismic ground motions at critical infrastructure and nuclear facilities and implement protective measures such as seismic isolation. The long-term goal is to evaluate the performance of virtual nuclear power plants and nuclear facilities to a wide range of external hazards including multiple event scenarios.

The presentation in the third session provided an overview of the SCEC Special Projects that have a direct relationship to engineering applications. These include the Uniform California Earthquake Rupture Forecast Version 3 (UCERF3) that provides the basis for identifying potential future earthquakes; the Collaboratory for the Study of Earthquake Predictability; and the Community Modeling Environment, which includes three components: the Broadband platform (BBP); the CyberShake platform and the High-F platform. Using various individual ingredients, SCEC has generated on the order of 235 million seismograms per model at 283 sites in the greater Los Angeles region, which were used for developing the hazard model.

This model deals only with frequencies up to 1 Hz. In order to attain higher frequencies of engineering interest there is a push for conducting physics-based deterministic simulations up to 5 Hz in 2015, and physics-based stochastic simulations to 5 Hz by 2018 and even higher, using empirical stochastic approaches.

Another important engineering-related activity at SCEC concerns ground motion simulation validation, since any practical application of simulation methods requires application-specific validation. Also, and most importantly, application-specific validation gauntlets must be designed collaboratively by earthquake scientists and engineers, including practicing engineers. Validation activities have been undertaken for the Broadband platform and for the High-F platform. These are coordinated by the Ground Motion Simulation Validation technical activity group, whose goal is to develop and implement, via collaboration between ground motion modelers and engineering users, validation gauntlets for engineering applications. Metrics used for these validations include elastic and inelastic spectral accelerations/displacements, nonlinear building response, and duration-sensitive geotechnical systems. There is a parallel effort to utilize the ground motion simulations in practical applications. This effort, being led by the Committee on the Utilization of Ground Motion Simulations, has as its main objective to develop long-period response spectral acceleration maps for the Los Angeles region for inclusion in NEHRP and ASCE 7 Seismic Provisions and in the Los Angeles City Building Code.

Needs

Based on the morning presentations and discussions, the afternoon session was devoted to discussing (both short-term and long-term) research needs, desirable actions and developments that could help (i) improve our understanding of the extent and importance of SSI effects, and (ii) develop the methodologies to incorporate such effects into the analysis and design of infrastructure systems when these effects are significant. The participants felt strongly that in order to attain these goals, there is need for (1) more/better instrumentation of building structures and other infrastructure, and (2) increasingly more realistic simulations accompanied by validations that use available existing data and data from newly instrumented infrastructure systems.

There were a number of specific comments and suggestions offered during this session. These include the following:

Issues related to the understanding of SSI

- Lack of recorded ground motion near buildings presents a challenge for validation. Need additional instruments in the vicinity of buildings to be able to compare basement motion with recorded free field motion.

- “Blind validation” can also be useful in validation efforts, e.g., Parkfield blind-prediction experiment.
- Need additional instruments in building basements to be able to determine rotational motion in addition to translations.
- Knowledge of the structural response, and basement translation and rotation as well as relative basement motion compared to free field motion are essential for inferring the extent and importance of SSI.
- What is the effect of neighboring structures on SSI?
- Simulations needed also to validate the measurements.

Issues related to ground motion

- Need better understanding of the nature of basin and seismic wave propagation in the near field: fundamental information on how waves propagate through the soil, surface waves, depth variation, etc., to be used for the excitation of extended structures.
- Knowledge of ground motion at different depths can be very useful. Numerical modelers could do this.
- Characterization of soil in the top ~30 m can be very important. Seismologists don’t know enough but engineers may know more. Collaboration between the two groups is important and can be used to improve SCEC velocity models.
- Frequency dependence of attenuation is important. (Already being studied at SCEC).
- Need to better understand the effects of vertical acceleration on the structure and on SSI phenomenon.
- Need to account for spatial variation of ground motion: wave passage problem, coherency. Two parts: (1) Need to represent the spatial variability of ground motion, and (2) study how the coherency affects the SSI analysis; research is needed to see how to address incoherency.
- Do engineers want access to the SCEC synthetic seismograms? (Engineers: Yes, if the seismograms cover a wide-enough period band).
- Need for stochastic analysis of ground motion, to incorporate uncertainty, especially at higher frequencies. SCEC already has activity in this direction.
- Need statistical analysis for variation of ground motion over the height of the basement.
- Need software tools that can incorporate multi-support excitation. Important to input different time-series into the analysis.

Issues related to engineering practice

- Identify specific target performance goals, e.g., target risk.
- For engineering practice need simple models. But how simple is too simple of a model? For instance, for soils don't want to ignore the physics when modeling the springs/dashpots/piles etc.; most of the springs are based on outdated empirical models. Each component of the empirical models needs to be validated. Need to know when to abandon unreasonable results.
- Need to encourage practitioners to start thinking about SSI analysis. 90% of practice assumes fixed base, which avoids SSI but is not always conservative. Most structural engineers are not able to represent SSI. Most will consider SSI analysis if they are provided with a simple SSI model.
- Need better representation of design spectrum for damping ratios other than 5%. In SSI we always start with uniform hazard response spectra (UHRS) at 5% damping, but we need to consider other damping ratios, which can change the spectrum significantly.
- In research, it would be nice to have time-series for given hazard levels and bypass the UHRS procedures.
- Need to encourage practitioners to start thinking about SSI analysis.

A general observation:

- Simulated ground motions existed for many years, but they were not really used until verified systematically and validated against data through projects like the BBP validation project. The situation might be similar for SSI: an organization like NIST needs to undertake a process to bring together interested engineers and scientists and look at the SSI problem systematically, validate, verify codes, etc. For instance, the current SSI software gives different results for the exact same inputs even in linear analysis. Verification of these codes could be a first step.

And a closing remark offered in response to the various points raised during the discussion:

- It will be useful to have a numerical lab for simulation at as high resolutions as we can get for this group (engineers interested in SSI). Will need recommendations from the group for specific sites.

As a follow-up to this workshop, it would be useful to start exploring whether and how SCEC could help activate the recommendations contained in the last two observations.