# International Workshop on Uncertainties in Nonlinear Soil Properties and their Impact on Modeling Dynamic Soil Response
# Position Paper by

**Boris Jeremić, University of California, Davis**
`jeremic@ucdavis.edu`

The topics suggested for discussion are very well chosen, are quite interesting, and if properly discussed and documented, will greatly benefit future of modeling dynamic soil responses. The topics addressed in this paper look at the problem from the computational simulation tools point of view. The idea of using simulation tools (computational models) in assessing future performance of infrastructure objects (bridges, buildings, port structures, dams...) is very much valued and is thus used to filter comments given below.

The computational tools need to be hierarchical in nature, from very simplistic ones, usually used in initial phases of the design, to the very sophisticated ones that are used to assess performance of infrastructure objects during catastrophic loads. This set of hierarchical models should live concurrently with the physical system they represent. Moreover, developed models (of different sophistication) will provide designers, owners and operators with the capabilities to assess operations and future performance. This seems to be very important as it will empower designers, owners and operators to make educated decisions on current state or future performance of objects. The hierarchical set of models should be able to foretell the state of the object (deformations, safety, limit loads...) for both service and catastrophic loads. In addition to that, observed performance can (and should) be used to update and validate models through simulations. This additional benefit of being able to validate models goes along well with a much wider goal of verification and validation of the developed simulations tools (c.f. Oberkampf et al. [5] and Roach [6]).

The ideas, views and comments expressed in the remainder of the paper are related to the following topics:

- *Desired Model Forms for New Models:* New models need to be developed in hierarchical fashion. This will make it possible to assess performance measures in a hierarchical fashion. For example simple elastic–perfectly–plastic model that only requires friction angle on one end to sophisticated Manzari–Dafalias model (e.g. [4]) that requires more than 15 parameters, on the other end of sophistication can both be very useful. One should be able to use both models (and all the variants in between, c.f. Jeremić and Yang [3]) to assess performance of infrastructure objects with required/available degree of confidence and accuracy.
- *Incorporating Nonlinear Soil Data into NEES:* Validated models are already available within the NEESgrid simulations platform OpenSees, and further developments are forthcoming.

The performance based design requires a set of hierarchical models. Each level of complexity can satisfy certain simulation/performance requirements. For example for simple site response, single phase soil the simplest material models might be sufficient to illustrate basic site amplification effects. Figure 1, obtained by using our DRM (c.f. Yoshimura et al. [8]) implementation in OpenSees, shows vertical wave propagation through stiff (dense sand) and soft (soft clay) soils subject to the same earthquake. The result shows that

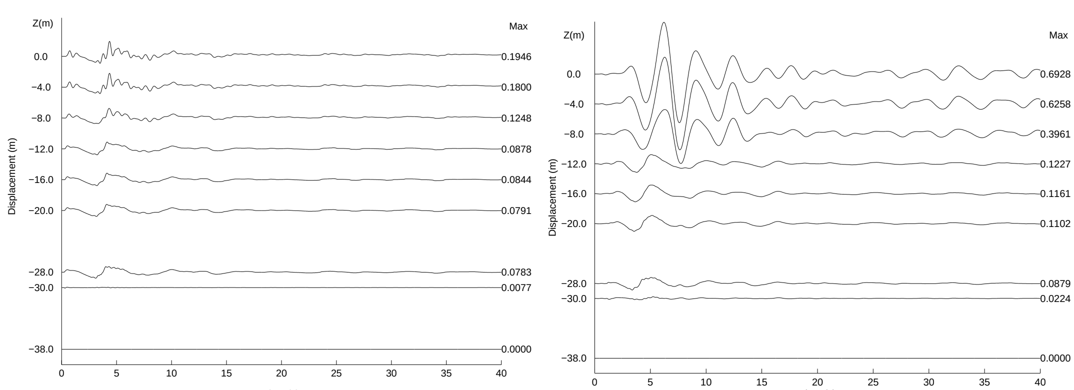


Figure 1: Seismic wave propagation resulting from the same earthquake acting on a stiff and soft soil site.

the soft soil site has an increase in surface deformation of 3.5 times than that one of the stiff site for this particular earthquake (one of Kobe records). The response was obtained using very simple models since only friction angle and shear strength was known for sand and clay, respectively.

Similarly, the simulation of site response using total stress or effective stress analysis can sometimes make a difference. In particular, the issue of damping can be attributed to coupling of solid and fluid phases (fluid phases include water but also the air in the pores). For example, if one examines the discretized form (finite elements) of equilibrium and mass balance differential equations for coupled, solid–fluid porous material:

$$\begin{bmatrix} (M_s)_{KijL} & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & (M_f)_{KijL} \end{bmatrix} \begin{bmatrix} \ddot{\bar{u}}_{Lj} \\ \ddot{\bar{p}}_L \\ \ddot{\bar{U}}_{Lj} \end{bmatrix} + \begin{bmatrix} (C_1)_{KijL} & 0 & -(C_2)_{KijL} \\ 0 & 0 & 0 \\ -(C_2)_{LjiK} & 0 & (C_3)_{KijL} \end{bmatrix} \begin{bmatrix} \dot{\bar{u}}_{Lj} \\ \dot{\bar{p}}_L \\ \dot{\bar{U}}_{Lj} \end{bmatrix}$$
$$+ \begin{bmatrix} (K^{EP})_{KijL} & -(G_1)_{KiL} & 0 \\ -(G_1)_{LjK} & -(P)_{KL} & -(G_2)_{LjK} \\ 0 & -(G_2)_{KiL} & 0 \end{bmatrix} \begin{bmatrix} \bar{u}_{Lj} \\ \bar{p}_L \\ \bar{U}_{Lj} \end{bmatrix} = \begin{bmatrix} (\bar{f}_s)_{Ki} \\ 0 \\ (\bar{f}_f)_{Ki} \end{bmatrix}$$

one can note that damping terms for this coupled system are only present if the subtensor $(C_1)_{KijL} = (C_2)_{KijL} = (C_3)_{KijL}$ are present, and that is the case only if fluid displaces relative to the solid, as seen from the equation below ($n$ is porosity and $k_{ij}$ is a tensor or permeabilities):

$$(C_1)_{KijL} = (C_2)_{KijL} = (C_3)_{KijL} = \int_\Omega N_K^{u,U} n^2 k_{ij}^{-1} N_L^{u,U} d\Omega$$

The consequence is that the only energy dissipating mechanism in geomaterials are either stemming from inelastic deformation (from the elastic–plastic stiffness tensor $K^{EP})_{KijL}$ or from coupling of fluid and the solid (from tensors $(C_1)_{KijL}$, $(C_2)_{KijL}$, and $(C_3)_{KijL}$). The above formulation is fairly general and is available within the OpenSees platform (e.g. Jeremić and Liu [2]). Of particular interest is the reliance on mixed unknown field (consisting of $\bar{u}_{Lj} \rightarrow$ solid displacements $\bar{p}_L \rightarrow$ fluid pressures $\bar{U}_{Lj} \rightarrow$ fluid displacements) for accurate solution to the problem. Figure 2 shows results of viscous coupling for a vertically propagating wave in fully saturated porous medium (saturated soil) for different values of permeability. It is obvious that the

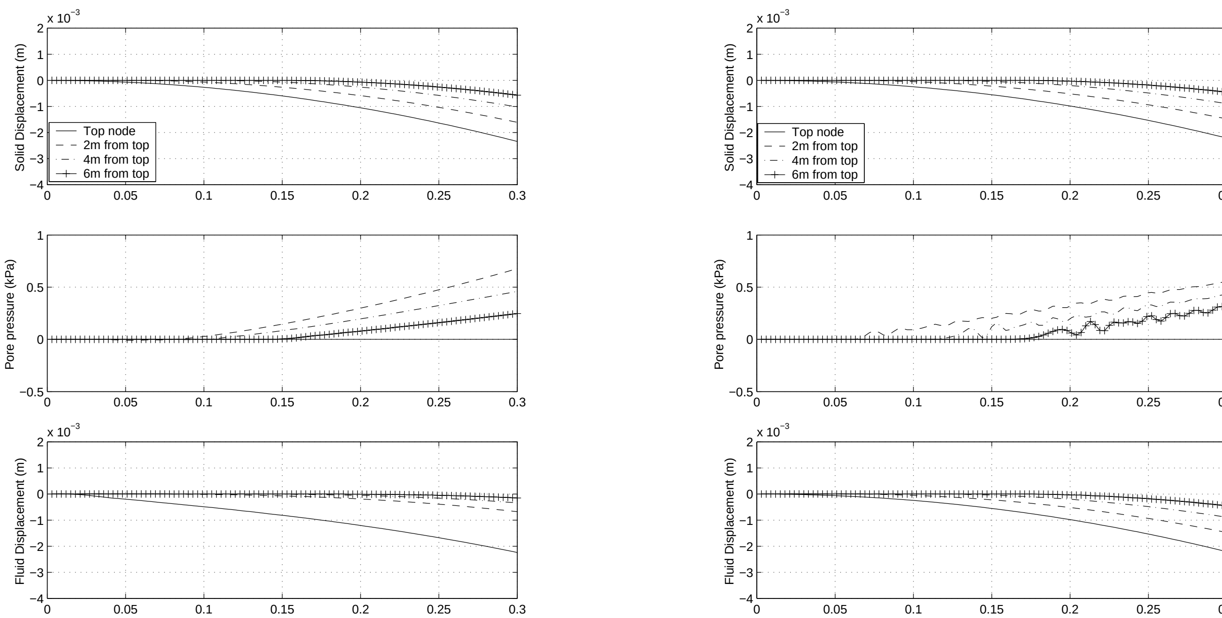


Figure 2: Viscous coupling for a vertically propagating wave in two soils with different permeability, left soil has $k = 10^{-3} m/s$ while the one of the right has $k = 10^{-5} m/s$.

permeability will greatly affect the response (given in terms of soil displacements, pore fluid pressures and fluid displacements).

Related to that is the use of somewhat advanced models for assessing the traditional shear modulus (secant) dependence on shear strains. For example Figure 3 shows the variation of $G/G_{max}$ with shear

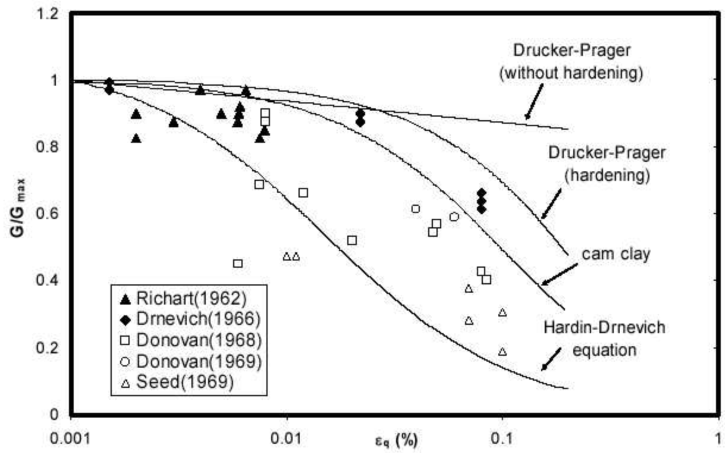


Figure 3: Variation of Shear Modulus with Shear Strain for Soil

strain as predicted by Hardin-Drnevich equation (c.f. [1]) and by different plasticity models with previously published experimental observation (e.g. Seed and Idriss [7]).

There are number of other examples where a hierarchical approach to material modeling can be successfully used to achieve desired (required) performance levels. All models based on rational mechanics can be used and the degree of sophistication governs the amount of information that can be expected from the simulations.

The main question that needs to be addressed, however, and is transcending all of the discussion topics is this: **What are we doing in preparing a new generation of civil engineers to deal with an increasingly complex engineering field (dealing with multi-physics, hierarchy of models, information technologies, NEESgrid...)?**

# References

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