A NEWLY GROWING APPROACH TO RIGOROUS MODELING OF SSI

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To capture the effects of the underlying soil on the overlying structure in the occurrence of dynamic loads such as earthquakes, reciprocating machinery, blasts, etc., beside conventional methods of analysis which mostly include replacing the soil with springs and dashpots, direct methods exist which serve to satisfy the necessity of exact responses for high importance and critical structural systems. These methods, which as a result of their being hard to handle while exact in responses are also called *rigorous methods*, make use of numerical simulations through e.g. finite elements to model each portion of the media with its specific characteristics. This way, no impedance or stiffness needs to be calculated since the structure is placed directly on the soil and interacts with it with no intermediary. Considering seismic waves throughout the soil, things get a bit more complicated as a result of the possible inherent reflection and refraction caused by the soil to these waves. This will lead to looking for a logical method of truncating the far-field out of the soil domain. To obtain this aim, the Scaled Boundary Finite Element Method (SBFEM) is applied in this research. To replace the far-field with its reaction forces, Equation 1 is used (Wolf & Song, 1996):

$$\{R(t)\} = \int_0^t \left[M^{\infty}(t-\tau)\left\{\ddot{u}(\tau)\right\}\right] d\tau \tag{1}$$

where R is the time-pulse dependent reaction force, M^{∞} is the unit impulse response matrix, and $\ddot{u}$ is the earthquake acceleration in each time step. The discretization of the whole system into near- and far-fields and the superstructure is illustrated in Figure 1.

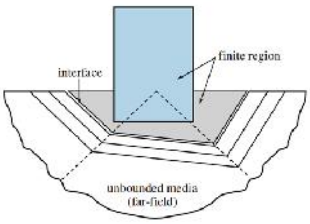
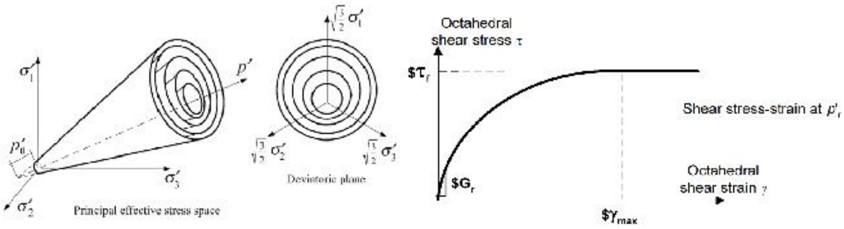


Figure 1. Decomposition of the soil-structure system into three sub-regions (after Genes, 2012)

The total equation of motion (Equation 2) is used to engulf Equation 1 to yield the final solution scheme for the far-field (Wolf, 2003).

$$\begin{bmatrix} M_{ss} & M_{sb} \\ M_{bs} & M_{bb} \end{bmatrix} \begin{Bmatrix} \ddot{u}^t{}_s(t) \\ \ddot{u}^t{}_b(t) \end{Bmatrix} + \begin{bmatrix} K_{ss} & K_{sb} \\ K_{bs} & K_{bb} \end{bmatrix} \begin{Bmatrix} u_s^t(t) \\ u_b^t(t) \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ -\{R(t)\} \end{Bmatrix} \tag{2}$$

For the near-field, the site is supposed to consist of once sand and once clay using the UCSD soil constitutive model which will be embedded in the finite elements. Details of this constitutive model are too extravagant for the scope of this abstract yet will be discussed in full details in the paper. The sample principle effective stress, deviatoric plane and octahedral shear stress versus shear strain for the sandy soil of this model are depicted in Figure 2. It should be noted that the study is carried on both sandy and clayey fields.



(a) (b)

Figure 2. (a) USCD soil model in principal effective stress space and deviatoric plane, (b) Octahedral shear stress vs. shear strain (after Yang et al., 2008)

The programming is done in the OpenSees software and through the Active Tcl coding language. The analyses are run for displacements and base reactions of the superstructure on drained and undrained sand, and on clay. It is observed that the drainage of the soil has important effects on structural as well as unit impulse responses. This study serves to suggest a new approach possible to analyse SSI problems rigorously which is at times necessary for large-scale and/or high importance structures such as power plants. Results are verified with other SSI solution techniques and manifest desirable accuracy. Table 1 represents a comparison of results achieved by Celebi et al., (2012) using a conventional constitutive model for the same problem in which the truncated far-field effects is only overlooked.

Table 3. Maximum displacements of the structure on elastoplastic soil with different constitutive models (m)

Height (m)	Mohr-Coulomb, low compaction	Mohr-Coulomb, medium compaction	Mohr-Coulomb, high compaction	UCSD, medium clay	UCSD, undrained sand	UCSD, drained sand
-2	-	-	-	0.031	0.041	0.019
0	0	0	0	0.018	0.031	0.061
3	0.082	0.038	0.028	0.053	0.042	0.069
6	0.168	0.077	0.067	0.103	0.101	0.111
9	0.240	0.115	0.105	0.138	0.137	0.135
12	0.292	0.148	0.136	0.163	0.166	0.152
15	0.325	0.168	0.156	0.186	0.188	0.170

As is observed, results are in similar ranges although values are different which is because the constitutive model is tuned with detailed behaviour of the environment, namely drained and undrained sands, clay. Logical responses suggest that the new scheme of SSI analysis may find its way through approaches to get exact structural responses during dynamic loading when the soil condition is such that SSI occurs. The near-field and the far-field are both engaged in the overall displacements and drifts of the superstructure and the effects of soil drainage, and possible cohesion are seen.

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