SOIL-STRUCTURE INTERACTION ANALYSIS WITH NONLINEAR SUBSTRUCTURING METHOD

Behtash JAVIDSHARIFI
Construction Superintendent, Fars Regional Electricity Company, Shiraz, Iran
b.javidsharifi@sutech.ac.ir

Hossein RAHNEMA
Assistant Professor, Shiraz University of Technology, Shiraz, Iran
rahnema@sutech.ac.ir

Sassan MOHASSEB
Professor, Tehran University, Tehran, Iran
smteam@gmx.ch

Keywords: Soil-Structure Interaction, Substructuring, Nonlinearity, Constitutive Model, Structural Responses

For more than a century researchers have been aware of the impact of the underlying soil on structural responses. The studies began primarily with inspecting static effects and settlements of the structure along with stress distribution caused by the superstructure loads through the soil. It was soon discovered that it is especially during dynamic loadings that the underlying soil shows itself off and can be entangling to engineers. To inspect the effects of the soil, one common approach is to model the soil with springs and dashpots under the structure, which is called *substructuring* method. The substructures are modelled as a series of springs and dashpots in parallel and serial and their locations are chosen to fit the system characteristics best. Figure 1 depicts a simple model taking up this approach.

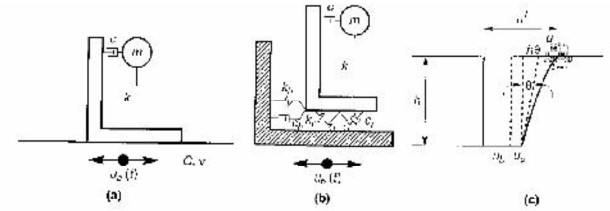

Figure 1. Substructuring method of SSI analysis (after Wolf, 1985)

The total displacement then would be calculated as in Equation 1:

$$u^t = u_b + u_o + h\theta + u \tag{1}$$

where *u*'s can be observed on Figure 1. Since superposition is performed in this approach, no nonlinearity is assumed in the solution. To overcome this shortcoming, the behaviour of the soil-replacing springs may be addressed which is shown schematically in Figure 2.

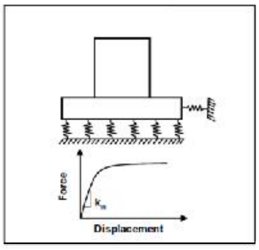

Figure 2. Substructuring method of SSI analysis with nonlinearly behaving springs (after Raychowdhury, 2008)

The UCD constitutive model is chosen for the behaviour of the nonlinear soil. To use this model in the present solution scheme, conventional fundamentals of shallow foundations bearing capacity have been used as in Equation 2 (Terzaghi, 1943):

$$q_{ult} = cN_c F_{cs} F_{cd} F_{ci} + \gamma D_f N_q F_{qs} F_{qd} F_{qi} + 0.5\gamma B N_\gamma F_{\gamma s} F_{\gamma d} F_{\gamma i} \quad (2)$$

For whose bearing capacity factors namely those of shape and depth and of the foundation and inclination of the load are calculated through Meyerhof's method (1978). In the above formulation, q_{ult} is the ultimate bearing capacity for unit area of the footing; c is the cohesion of the underlying soil of the foundation in case cohesive; B dimension of the foundation and N's are bearing capacity factors. F's are supposed shape, depth and inclination factors. The soil is supposed to be once sandy, once clayey and once clayey sand with various density and compaction conditions. The structure is supposed to be an RC frame with similar beams and columns cross sections whose material properties are shown in Table 1 and Table 2.

Table 1. Mechanical properties of concrete for nonlinear structure

Mechanical Properties	Characteristic Strength (kPa)	Strain in Maximum Strength	Crushing Strength (kPa)	Strain before Crushing	Tension Strength (kPa)
Core Concrete	24×10^{-3}	0.0024	5.6×10^{-3}	0.015	0
Cover Concrete	21×10^{-3}	0.002	5×10^{-3}	0.005	0

Table 2. Mechanical properties of steel for nonlinear structure

Mechanical Properties	Yield Stress (kPa)	Initial Modulus of Elasticity (kPa)	Strain Hardening Ratio
Reinforcing Steel	420×10^3	2×10^8	0.01

Programming is done in MATLAB and active Tcl environments and the OpenSees software is used to run the analyses. Displacements and base reactions are observed after the analyses are performed. It is observed that the linear assumption of SSI may be correct but strictly depends on the behaviour phase of the soil and once nonlinear strains start to accumulate in the soil, the responses may be considerably different from those of conventional solution approaches. Mechanical properties of the underlying soil too play an important role in structural responses as well as base shears and reactions. The accordance of the input motion with soil properties plays the most important role in interactional responses causing the materials to possibly get into the nonlinear phase of behaviour. Table 3 suggests a comparison between results of this solution technique and another carried on by finite element modelling taking into account the Mohr-Coulomb constitutive model for the soil in Plaxis.

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	UCD, low compaction	UCD, medium compaction	UCD, high compaction
-2	-	-	-	0	0	0
0	0	0	0	0.025	0.015	0.013
3	0.082	0.038	0.028	0.057	0.052	0.028
6	0.168	0.077	0.067	0.104	0.075	0.071
9	0.240	0.115	0.105	0.122	0.099	0.088
12	0.292	0.148	0.136	0.139	0.121	0.108
15	0.325	0.168	0.156	0.149	0.134	0.118

This method of analysis makes engineering calculations easier to be performed while it provides accurate results taking into account the real behaviour for the soil. Finite element modelling of the soil which, although a high-precision technique, is rather time consuming and at times a challenging approach to model the behaviour of the soil along with the structure may be efficiently replaced by the modified substructuring (i.e. nonlinear) method to result in fast modelling and analysis procedures and reliable outcomes.

REFERENCES

Meyerhof GG and Hanna AM (1978) Ultimate bearing capacity of foundations on layered soils under inclined load, Canadian Geotechnical Journal 15.4: 565-572

Raychowdhury P (2008) Nonlinear winkler-based shallow foundation model for performance assessment of seismically loaded structures, ProQuest

Terzaghi K (1943) Theoretical soil mechanics

Wolf JP (1985) Dynamic soil-structure interaction, Prentice Hall Int.