Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 19-20, 2022

Auto-Generation Technique of Numerical Elements for Near-Far Field Soil in Three Dimensional Soil-Structure Interaction System

Choon-Gyo Seo [a*], Jin-Seob Kwon [b], Byung-Cheol Park [a], Gyu-Seong Woo [a], Yongsun Lee [a]
[a] *KEPCO Engineering & Construction, 269 Hyeoksin-ro, Gimcheon-si, S. Korea*
[b] *Korea Hydro & Nuclear Power, 1655, Bulguk-ro, Munmudaewang-myeon, Gyungju-si, Korea*
[*] *Corresponding author:seosck@kepco-enc.com*

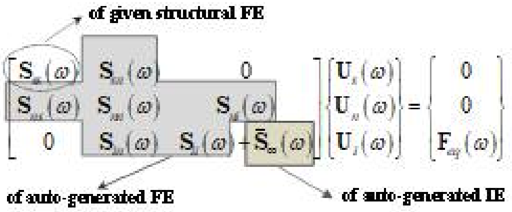
1. Introduction

The soil-structure interaction (SSI) analysis is basically performed using the linear complex response method in the frequency domain, and the SSI modeling methodology can be divided into two types: the substructure method and the direct method. The sub-structure method is a method to obtain the dynamic stiffness (impedance) of the soil due to the scattering field motion at the boundary between the massless structure and the soil, and to obtain the motion sequentially by combining the impedance with the dynamic stiffness including the structural inertia. The SASSI-based programs use this methodology [1]. On the other hand, the direct method directly models the structure and the near-field soil with finite elements, and the far-field soil is simulated by the artificial boundary. The KIESSI-3D is a representative program that realizes the unknown solution by combining both the dynamic stiffness and impedance of the two systems in a single algebraic equation [2].

In recently published technical standards [3,4], it is recommended to avoid the beam stick elements for numerical modeling of nuclear power plant structures, and to perform seismic response analysis by discretizing it in three dimensions. Compared to the past computational environment, high-performance hardware made it possible to process large amounts of data, and this is caused by the demand for precise seismic response of structures are increased. Furthermore, as the need for time-domain SSI analysis considering the application of seismic isolators under material nonlinearity of structure and soft soil condition, the time-domain direct method is also introduced for the analysis of the SSI system. The time-domain direct method is not much different from the frequency-domain direct method in terms of model development. However, the time-domain direct method has a disadvantage in simulating the dispersion effect of surface waves and requires a wider near-filed region to simulate the artificial boundary.

2. Methodology

In this paper, the automatic generation of 3D finite element of the near-field soil is discussed and a new technique is presented. It is applied in the computer program is KIESSI-3D which had been developed by domestic researchers and continuously updated for 30 years. The feature of this program is that it has a built-in artificial boundary modeled with a high-order dynamic infinite element, that can simulate well the wave propagation toward the soil medium to the infinite domain. This infinite element has the advantage of reducing the number of finite elements in the near field remarkably by minimizing the range of the near field. The SSI seismic response analysis in KIESSI-3D uses the frequency-domain algebraic equation as shown below.



(1)

The left side of the equation is divided into three regions to express the dynamic stiffness ($S_{ss}(\omega)$) of the structure, the dynamic stiffness ($S_{nn}(\omega)$, $S_{ii}(\omega)$) of the near field and the near-far boundary and the impedance($\overline{S}_{\infty}(\omega)$) of the far field, respectively. The subscript n denotes the degree of freedom that denotes the structure, i denotes the near-field region and ∞ denotes the infinity. The region including the near field and far field is modeled by automatic generation with the finite element and the dynamic infinite element respectively. This is a function that greatly relieves the burden of the analyst who models complicated soil region in three dimensions. The program automatically creates all numerical elements (finite-infinite elements) of the near-far soil region instead of user except the structure is modeled.

Fig. 1 shows the concept of mesh generation according to the near-field region shape during automatic finite element generation. If the structure area has an arbitrary shape, it is advantageous to model it in a radial type, and when the structure is in a rectangular shape, it is easy to model it in a grid type. Although the radial type method can be seen as a more general technique, it has a disadvantage that the finite element mesh size gradually expands in the radial direction. Since the requirement for the finite element grid size presented in the technical standards is also applied to model development for dynamic analysis of nuclear power plant structure, KIESSI-3D basically determines the mesh size by following formula:

$$h_o = \frac{1}{5}\frac{V_{s,\min}}{f_{\max}} \tag{2}$$

Where h_o is the reference mesh size of the horizontal finite element, $V_{s,\min}$ is the minimum value among the shear wave velocity of the soil layer, and $f_{\max}$ is the maximum frequency considered in the analysis. Fig. 1 shows the built-in functions of KIESSI-3D. These built-in functions provide that the horizontal mesh size is smaller as it approaches the structure and closer to h_o as it goes farther away. Since the divergent field response due to structure inertia appear sensitively near the structure, a fine-grained mesh near the structure is advantageous for simulating the dynamic behavior. That is, if the user designates the desired near-field range ($\alpha = D / R_o$), the number of horizontal mesh (N) can be determined, and the size of mesh can be automatically obtained by combining the log coefficient ($a = \ln(1+\alpha R_o / R_i)/N$) and the exponential function. Fig. 2 is a typical numerical model representing the automatic generation of finite elements in the near-field region around the structure. Although it is not shown in Fig.1 and Fig 2, KIESSI-3D also automatically creates dynamic infinite elements for the far-field.

3. Conclusions

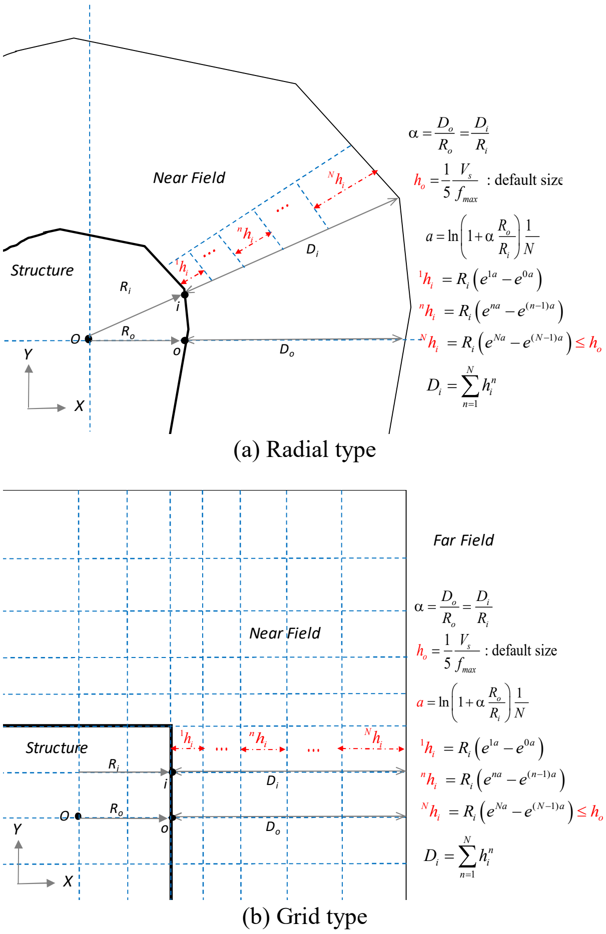
When creating a three-dimensional seismic response analysis model to consider the SSI effects, the various numerical elements corresponding to the near-far field region can be accurately and automatically generated without human error by this auto-generation technique. In addition, the multiple analysis models including stochastic input variables can be quickly and iteratively developed.

Acknowledgement

This study is financially supported by KETEP in Korea (Grant No. 20193110100020).

REFERENCES

[1] Farhang Ostadan, Nan Deng, “SASSI2010, A System for Analysis Soil-Structure Interaction”, 2012.
[2] C. G. Seo, J. M. Kim, “KIESSI-3D Program for Soil-Structure Interaction Analysis”, Computational Structural Engineering Institute of Korea, V25, 2012.
[3] ASCE/SEI 4-16, “Seismic Analysis of Safety-Related Nuclear Structures”, ASCE, 2017.
[4] KEPIC STC, “Seismic Isolation System”, Korea Electric Association, 2017.



(a) Radial type

(b) Grid type

Fig. 1. Two types of auto-generated finite elements for near-field soil medium

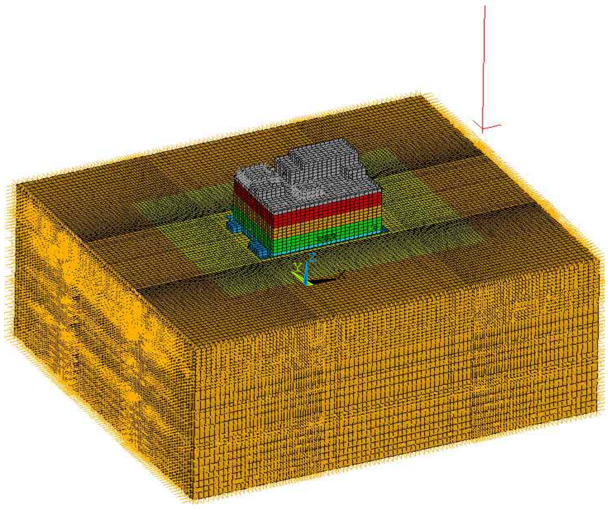


Fig. 2. Example of auto-generated finite element model for near-field soil medium