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Verification of Analysis Model for Soil-Structure Interactions Analysis

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1. Introduction

Due to significant advances in hardware and software, the latest technical standards for seismic analysis recommend three-dimensional finite elements model that can be accurately discretized numerically. Most of the seismic analysis models considering soil-structure interaction (SSI) of nuclear power plants were based on concentrated mass and beam element models in the past. Although these models have the advantage of reducing the analysis time, but that cannot get the response at the specific location within the structure and cannot reflect the torsional effect of the eccentric mass of the super-structure. In addition, the response of high-frequency modes cannot get adequately in a concentrated mass and beam element model due to the excessive reduction in degrees of freedom.

In this paper, a 3-D SSI analysis model was created and verified before performing probabilistic soil-structure interaction (PSSI) analysis. The verification method is to create a 3-D FE model according to the drawings using a general-purpose numerical analysis program and convert it to SSI analysis program to determine the suitability of the model. The verified model was analyzed by comparing the response to the concentrated mass and beam element model.

2. Verification of Analysis Model

This section describes the methods and results for verifying the 3-D SSI analysis model. The 3-D FE model and concentrated mass/beam element were made using the MIDAS CIVIL program, and the 3-D SSI analysis model was made using the ACS-SASSI program.

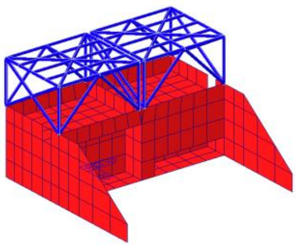
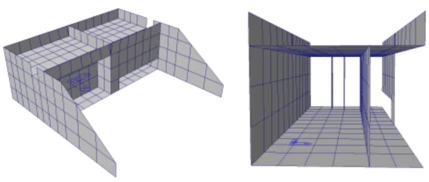


Fig. 1. 3-D FE model



(a) 3D plane (b) X-Z plane
Fig. 2. Sub-structure

2.1 Surface 3-D FE Model

The target structure is located in a nuclear power plant site and the 3-D FE model was created using the MIDAS CIVIL program according to the drawings. The embedded sub-structure part consists of a concrete foundation and concrete walls, and the super-structure is a steel structure with W-shaped sections for the main members and WT-shaped sections for certain bracing. The structure is water-fed through between the wing walls and the water-fed part is not embedded. The analysis model is shown in Figure 1 ~ 2.

2.2 Embedded 3-D SSI Model

When the boundary conditions of a structure's foundation is at the surface, the structural analysis method is simple and many analysis techniques and programs are available. However, for structures with embedded foundations condition, it depends a lot on how to consider the soil and the structure's degrees of freedom. The analysis technique [1] of the ACS-SASSI program used in this study is based on the flexible volume method in the frequency domain. In the flexible volume method, the dynamic solution is computed for the coupled structure excavated soil system defined by the differential complex dynamic stiffness obtained by subtracting the excavated soil from the basement. The difference between the dynamic complex stiffness of the two coupled subsystems, structure and excavated soil, characterizes SSI interaction effects for an embedded foundation problem.

The SSI analysis model of the target structure is shown in Figure 3, which is an embedded model with backfill on the ground around the structure. The SSI analysis model with backfill is shown in Figure 4.

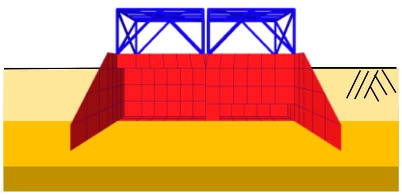


Fig 3. Embedded SSI model

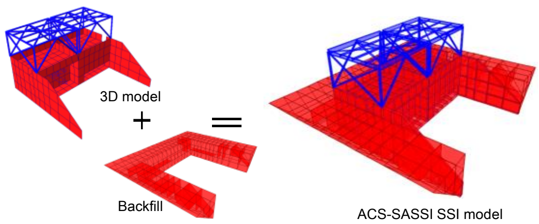


Fig 4. 3D SSI model with backfill

2.4 Verification of Surface model

Converting the 3D FE model to SSI model, the SSI model was verified by placing the boundary condition on the bottom without embedded the structure.

As the first verification method, the eigenvalue analysis was performed. The SSI model checked the transfer function to check the eigenvalues, and the results are shown in Table I. The eigenvalues are similar within 1%. In the Z-direction, the mass participation of the first mode is very low (3%) and is excluded from the comparison.

Table I: Comparison of eigenvalue analysis

Mode	Mode shape	Frequency(Hz)	
		FE model	SSI model
1	X-dir. First	11.689	11.768
2	Y-dir. First	14.193	14.111

As a second verification method, seismic analysis was performed and compared the FRS. (Figure 5 ~ 6) The responses of the two models fit well within the margin of error.

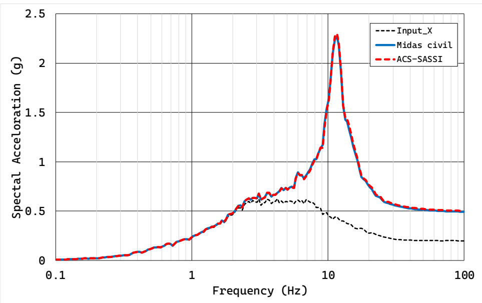


Fig 5. Comparison of FRS at top (X-dir., damping 5%)

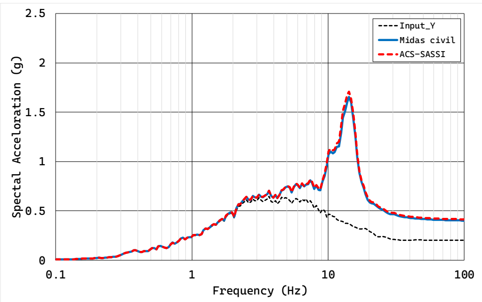


Fig 6. Comparison of FRS at top (Y-dir., damping 5%)

2.3.2 Verification of embedded model

The verified 3-D SSI analysis model was analyzed using the same input earthquake (horizontal PGA : 0.2g, vertical PGA : 0.13g) and soil properties with embedded condition for comparing with the existing concentrated mass and beam element model(Figure 7), and the results are shown in Figures 8 ~ 9. The results in the x-direction (Figure 8) show that the response of the concentrated mass-beam element model is slightly larger in the low-frequency band (below 5Hz), while the response of the 3D FEM is slightly larger in the high-frequency region (above 15Hz). However, the overall responses are similar.

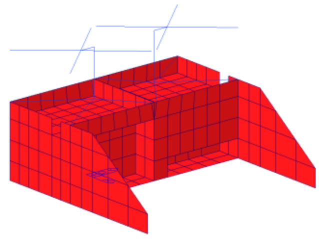


Fig 7. Existing beam-stick model

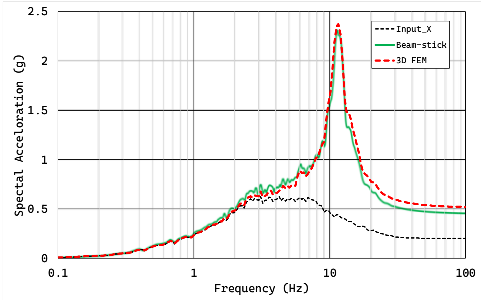


Fig 8. Comparison of FRS at top (X-dir., damping 5%)

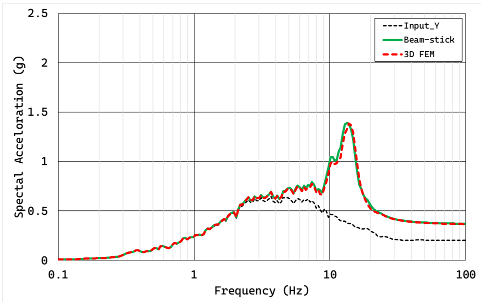


Fig 9. Comparison of FRS at top (Y-dir., damping 5%)

3. Conclusions

In this paper, a 3-D SSI analysis model was developed and the model was verified through two verification methods. The suitability of the SSI analysis model was checked by comparing the model that surface condition without the effect of SSI, and the model was verified by comparing the model.

For the surface model, the results were almost the same between different programs, confirming the suitability of the SSI analysis model. For embedded models, responses are some differences because of a characteristic of the modeling and the overall response is similar. In the future, the verified 3-D SSI analysis model will be compared with the existing deterministic analysis results through probabilistic SSI analysis in the future.

REFERENCES

[1] ACS-SASSI Option PRO for Probabilistic SSI, An Advanced Computational Software for 3D Dynamic Analysis Including Soil-Structure Interaction User Manual, Ghiocel Predictive Technologies, Inc., Pittsford, NY, 2019.

[2] MIDAS Civil, http://manual.midasuser.com/KR/Civil/940/index.htm, MIDAS IT Co., Ltd., 2023