



Site-Specific SSI Analysis for Deeply Embedded SMR using FVROM-INT

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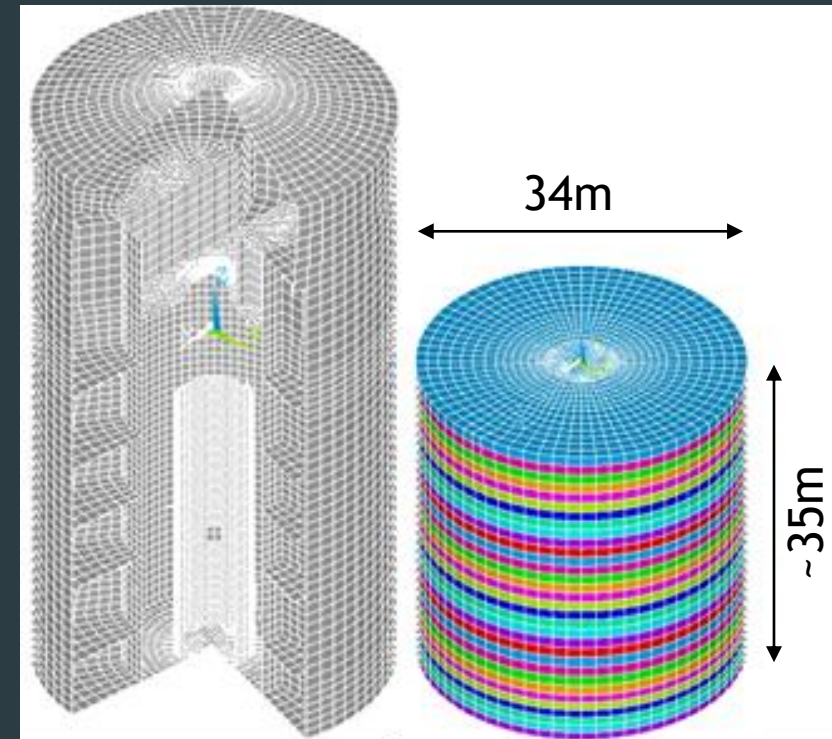
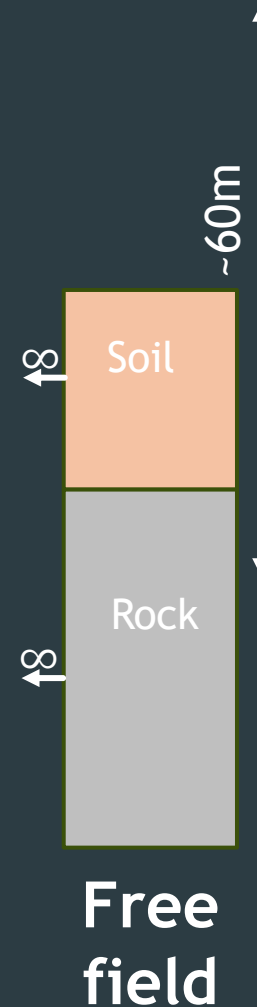
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Motivation

- ▶ Deeply embedded Small Modular Reactor (SMR)
- ▶ Site-specific soil conditions
- ▶ One-step structural design approach
 - Detailed structural model including design level modeling for directly obtaining design stress / forces
 - Considerations of design iterations and sensitivity analyses (Many repeat analysis cases!)
- ▶ Probabilistic SSI analysis considering variations in the structural model

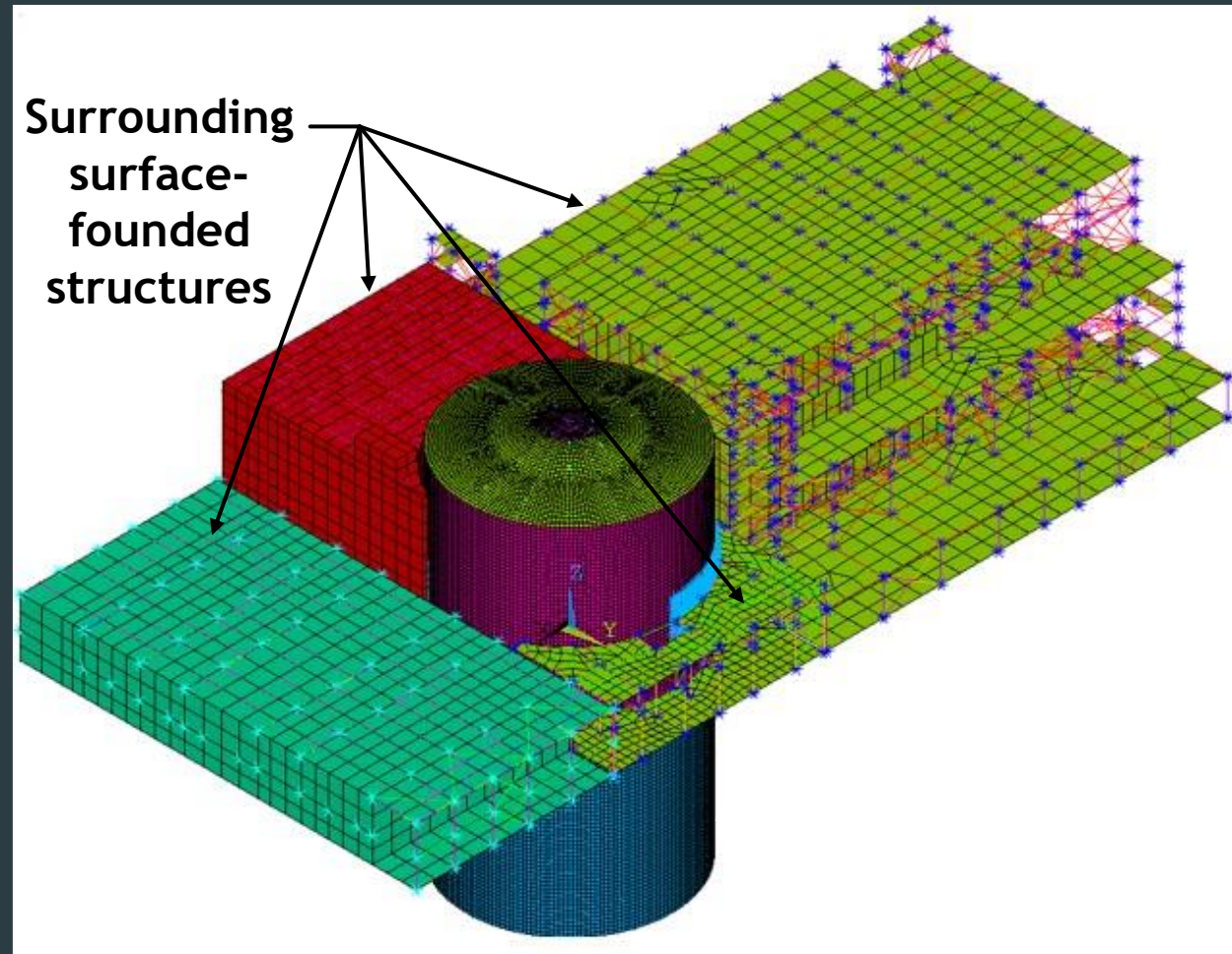
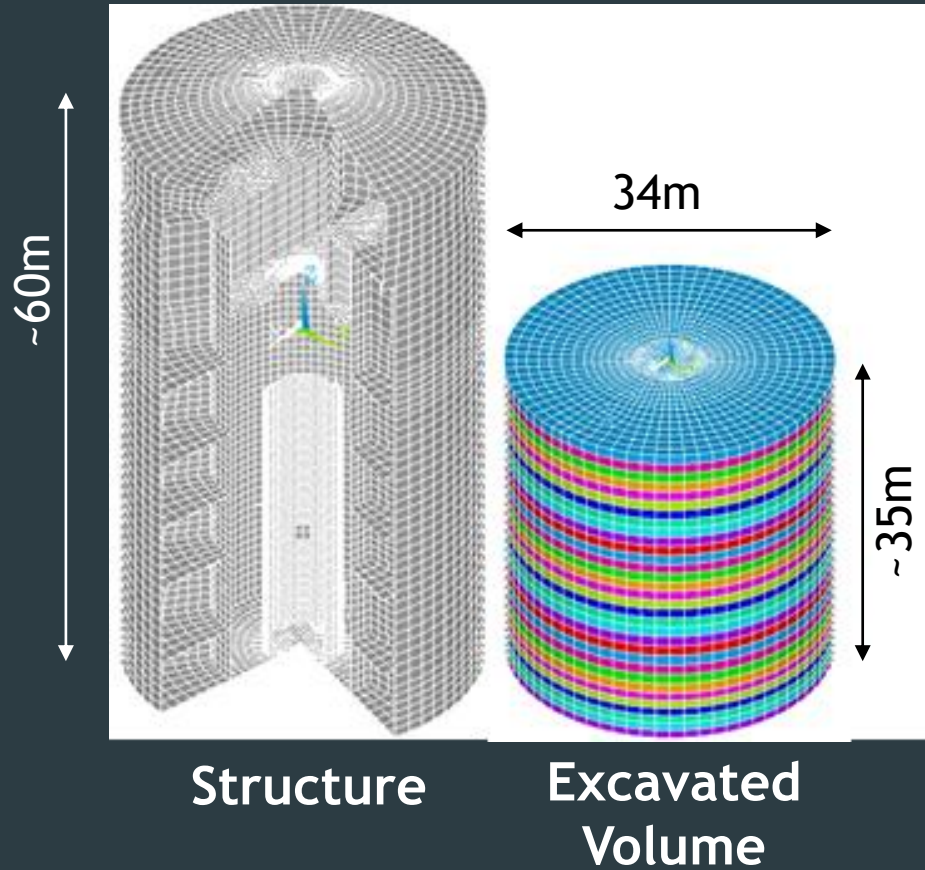


Structure

Excavated Volume



Soil-Structure-Interaction Model



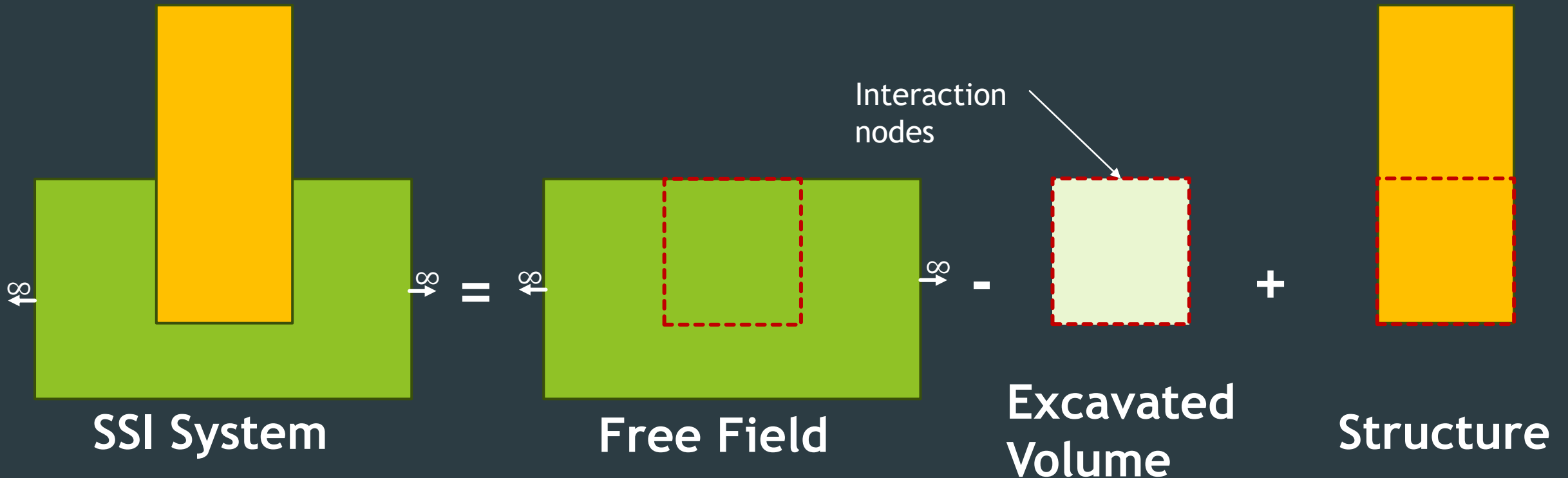


Design-basis model

- ▶ Because of the deep embedment and relatively small aspect ratio of the SMR, its seismic response is governed by its SSI response
- ▶ Design basis model considers:
 - ▶ Effective stiffness for the structural walls
 - ▶ Excavation support surrounding the structure
 - ▶ Full contact between soil/rock and structure over embedment height
 - ▶ Fully saturated soil conditions below GWT
- ▶ Additional sensitivity cases:
 - ▶ LB structural stiffness for the structural walls
 - ▶ Alternative excavation support surrounding the structure
 - ▶ Soil separation / loss of traction effects
 - ▶ Lower groundwater (unsaturated soil)
 - ▶ Etc.

Background

- ▶ SSI analysis of embedded structures in SASSI using substructuring approach
- ▶ Impedance calculation for the excavated volume is typically the most time consuming portion

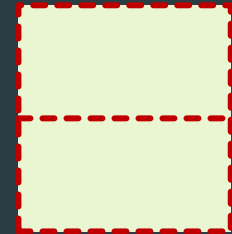
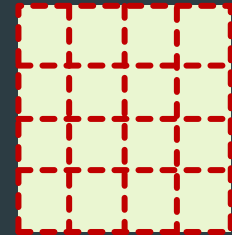




Background

Consideration of “Excavated Volume” in SSI analysis using SASSI (Impedance analysis)

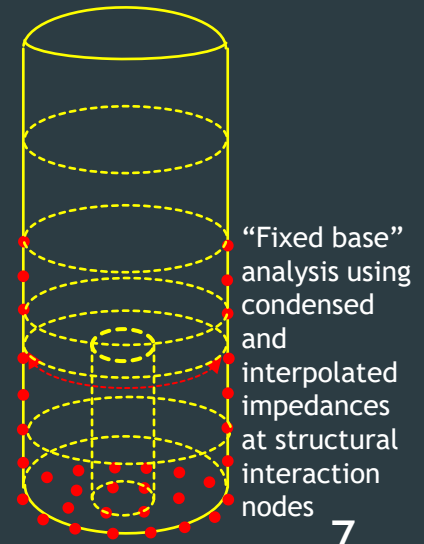
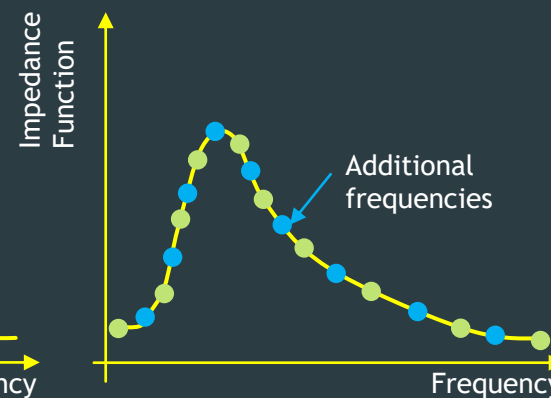
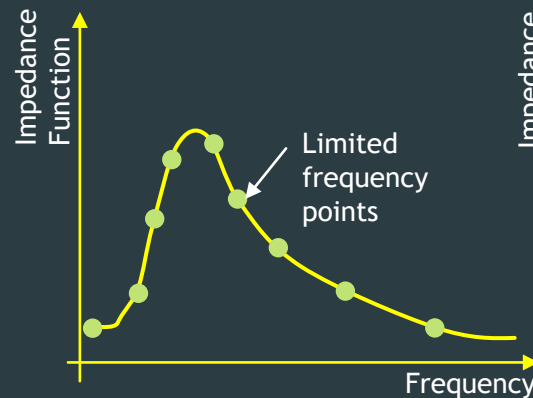
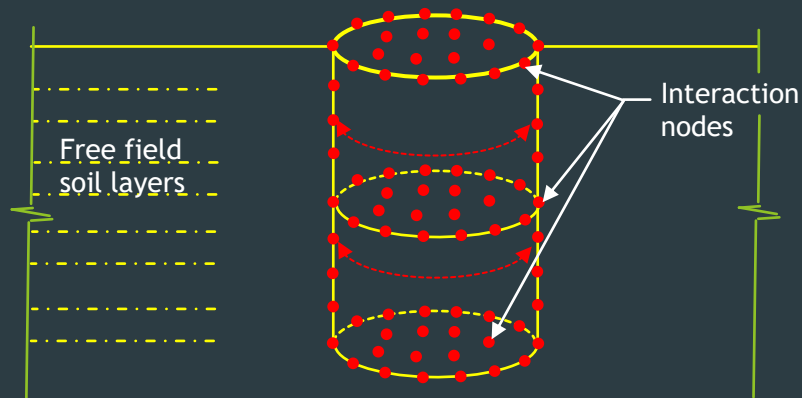
- ▶ Flexible-Volume (FV) approach
- ▶ [Extended] Subtraction method (ESM)
 - ▶ Computation of soil impedance at fewer nodes
 - ▶ Approximation of the FV approach
- ▶ Flexible Volume Reduced-Order Modeling (FVROM)
 - ▶ Applicable to both FV and ESM
 - ▶ Includes condensation of the excavated volume impedance solution at the structural interface nodes
 - ▶ With interpolation (recognizing that the impedance analysis to capture the response of the excavated volume can be done with fewer frequencies.





FVROM-Int Approach

- ▶ Implemented using ACS-SASSI version 4.3.4 (GP Technologies)
- ▶ Analysis steps:
 - Impedance solution for excavated volume at reduced frequencies
 - Static condensation of impedance functions at interaction nodes at reduced frequencies
 - Interpolation of the impedance functions at interaction nodes to full frequency set
 - SSI analysis for the structure at full frequency set





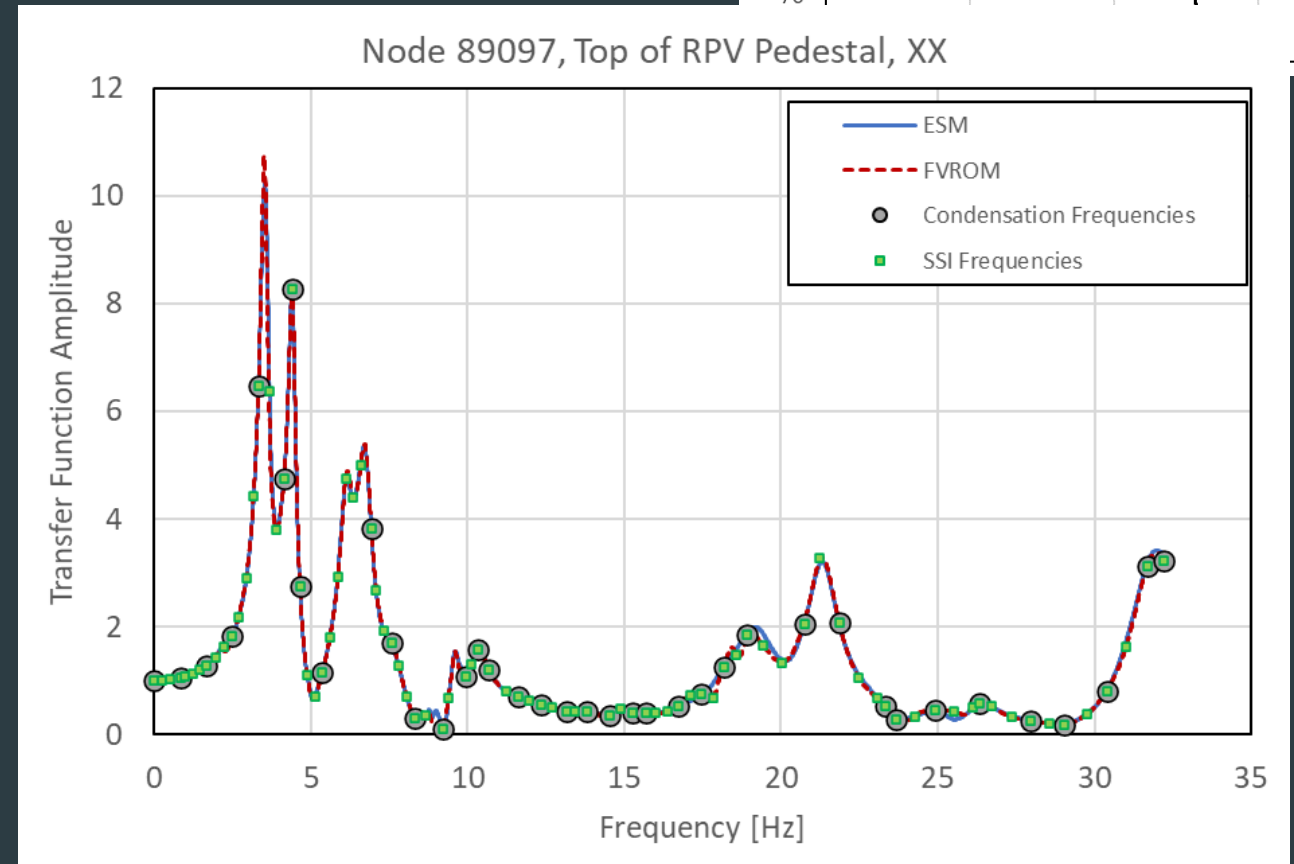
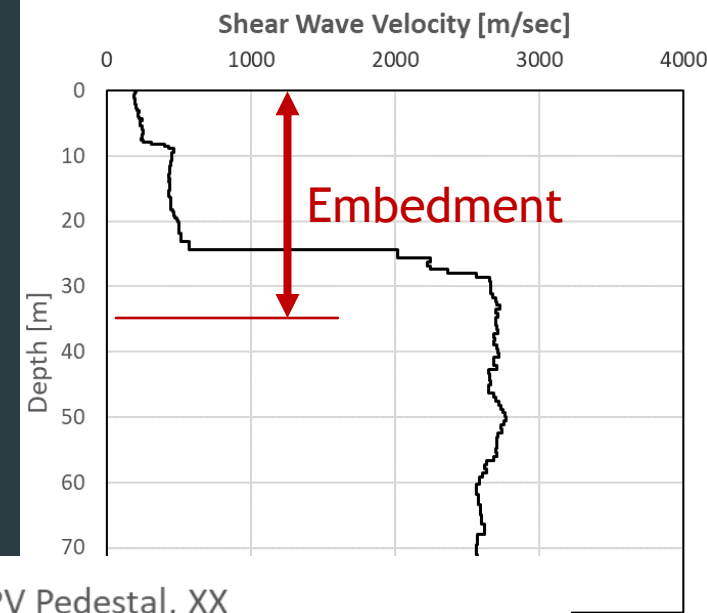
Challenges

- ▶ Initial model setup \ selection of interaction nodes and model interfaces to accommodate:
 - ▶ Future design changes
 - ▶ Sensitivity studies
 - ▶ Parameters included for the probabilistic SSI
- ▶ Selection of frequency set for the impedance analysis of the excavated volume and static condensation at the interaction nodes
 - ▶ Shape of the excavated volume
 - ▶ Soil profile and impedance contrasts within the excavated volume
 - ▶ Free field site response
 - ▶ Confirmation by comparing total solution with ESM or FV approaches



Example application - Transfer function results

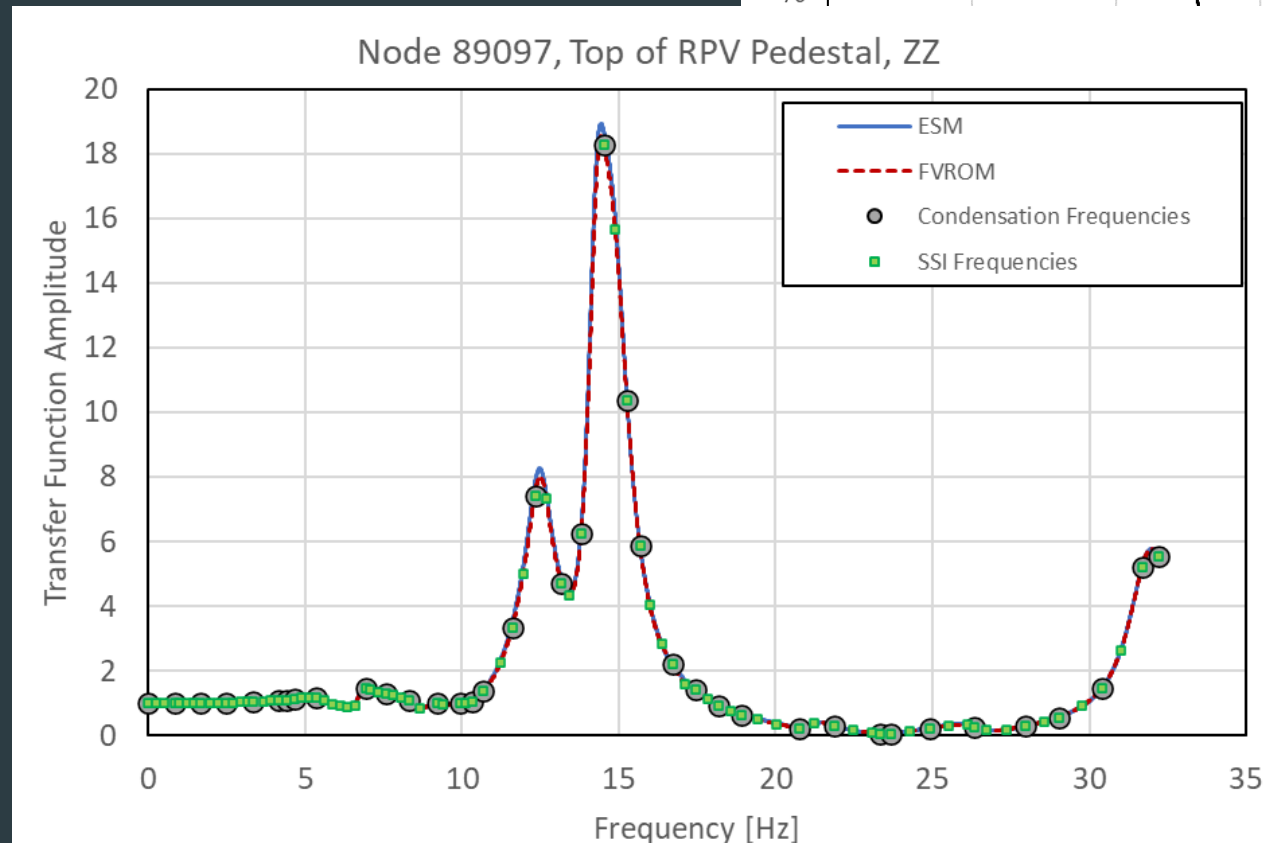
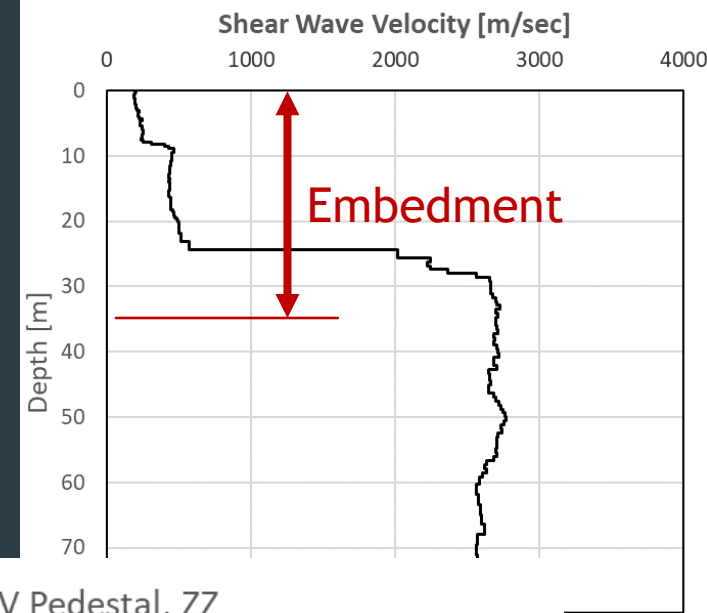
- ▶ SSI frequencies up to 33 Hz: 87
- ▶ Large impedance contrast within the excavated volume → 38 Condensation frequencies
- ▶ Interpolated impedance frequencies → 49
- ▶ Comparison with ESM approach without condensation







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Analysis Efficiency

Analysis Approach		Number of frequencies	Analysis time per frequency	Analysis time for full solution	Analysis time for a repeat analysis for a structural variation
ESM		87	4.75 hrs	17.2 days	17.2 days
FVROM-INT	Excavated soil solution and static condensation	38	3.75 hrs	 7.6 days	 0.6 days (factor of 30)
	Frequency-domain interpolation of the impedance matrix	49	0.5 hrs		
	SSI Analysis	87	0.17 hrs		



Conclusions

- ▶ Implementation of FVROM-INT approach for an embedded SMR
- ▶ Results are validated to be accurate by comparison with ESM method for one analysis case
- ▶ Significant saving in run time for repeat analysis, efficient implementation of design changes, sensitivity and probabilistic studies *without loss of accuracy*

