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## **NRC Meeting:** Update on Seismic Methodology Results



**Date: November 8, 2023**

**Presented By: Chuck Bullard and John Zhai**

**SMR, LLC, A Holtec International Company  
Krishna P. Singh Technology Campus  
One Holtec Boulevard  
Camden, NJ 08104, USA**

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# Meeting Agenda

- Introductions
- Purpose & Outcome
- Background and Previous Discussions
- Overview of Holtec SMR Seismic Methodology
- Results
- Questions
- Open Forum

# Introductions

- NRC Staff
- Holtec Staff
- Industry Consultant (SC Solutions)

# Purpose and Outcome

## ■ Purpose

To provide a high-level overview of the soil-structure interaction (SSI) methodology for Holtec SMR and discuss preliminary results and future plans.

## ■ Outcome

To obtain feedback from the NRC staff on presentation material and identify any potential risk areas or gaps in the SSI methodology for Holtec SMR.

## Background and Previous Discussions

- NRC Public meeting 9-27-22 (*Time-Domain Nonlinear SSI Analysis Using A Hysteretic Soil Model*)
  - ✔ Discussed proposed method of analysis for seismic design including the use of a non-linear soil model
  - ✔ Following the meeting, and in consideration of the presentation and discussion, the NRC staff has a high-level understanding of the proposed non-linear soil analysis method. The NRC staff did not identify any immediate concerns with the approach.
  - ✔ NRC noted that it has not previously approved a non-linear soil-structure analysis. Since this will be a ‘first-of-a-kind’ review, the NRC staff may ask additional questions to fully understand the approach and its implementation.

# Overview - Design Basis Seismic Ground Motion

- Seismic Design Response Spectra – Free field soil outcrop motion at the containment basemat elevation (EL. -86')

Horizontal directions

Frequency (Hz)	Acceleration (g)
0.1	0.0192
0.25	0.12
1.0	0.48
3.5	0.92
12	0.92
50	0.4
100	0.4

Vertical Direction

Frequency (Hz)	Acceleration (g)
0.1	0.0133
0.25	0.08
1.0	0.36
3.5	0.88
12	0.92
50	0.4
100	0.4

# Overview - Design Basis Soil Properties



## Shear Wave Velocities

Layer No.	Thickness (ft)	Depth (ft)	Shear Wave Velocity (ft/s)			Density (pcf)
			LB	BE	UB	
1	2	-2	635	900	1240	120
2	3	-5	705	1000	1415	120
3	15	-20	810	1150	1630	120
4	20	-40	985	1400	1980	120
5	20	-60	1130	1600	2265	120
6	20	-80	1200	1700	2405	120
7	20	-100	1255	1780	2520	120
8	20	-120	1305	1850	2620	120
9	20	-140	1360	1930	2730	130
10	30	-170	1410	2000	2830	130
11	Half Space		2825	4000	5660	150

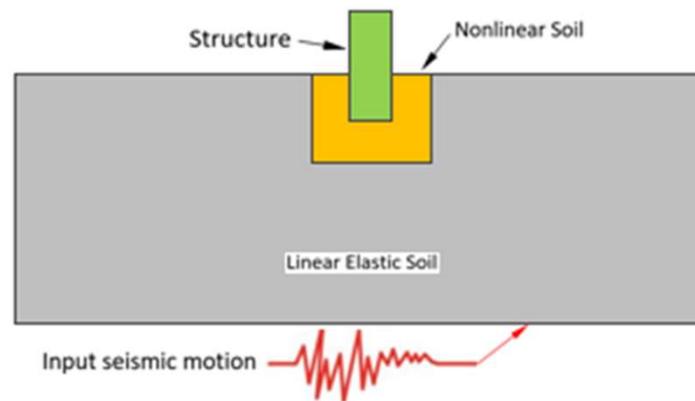
Note:  
1. All the layers of the three soil profiles have a Poisson's ratio of 0.35.

## Modulus Degradation & Damping

Depth (ft)	0-20		20-50	
	G/G <sub>max</sub>	Damping (%)	G/G <sub>max</sub>	Damping (%)
0.0001	1	1.5	1	1.2
0.0003	1	1.6	1	1.2
0.001	0.985	1.9	0.995	1.3
0.003	0.915	2.8	0.95	2
0.01	0.75	5.1	0.825	3.6
0.03	0.52	9	0.62	6.8
0.1	0.275	15.4	0.36	12.6
0.3	0.125	21.5	0.175	18.7
1	0.045	28	0.067	25
Depth (ft)	50-120		120-170	
	G/G <sub>max</sub>	Damping (%)	G/G <sub>max</sub>	Damping (%)
0.0001	1	1	1	0.8
0.0003	1	11	1	0.8
0.001	1	1.1	1	0.9
0.003	0.97	1.7	0.975	1.3
0.01	0.875	2.8	0.905	2.2
0.03	0.695	5.3	0.755	4.3
0.1	0.43	10.3	0.495	8.8
0.3	0.23	16.3	0.28	14.3
1	0.09	22.8	0.115	21

# Overview: Proposed Seismic Analysis Methodology

## ■ Proposed Holtec SMR SSI Analysis – Time Domain & Nonlinear



- Global soil behavior is equivalent linear elastic, which is modeled based on strain compatible soil properties obtained from SHAKE analysis
- Nonlinear soil model maybe be used locally in the region where SSI effect is strong with relatively large strain
- Structures are modeled as linear elastic materials
- Contact interfaces are defined to account for geometric nonlinearity

# Overview: Validation of Soil Material Models



- Two hysteretic soil material models will be used in the LS-DYNA SSI analysis:
  - \*MAT\_232 – Equivalent linear elastic material model used to predict the global behavior of the soil site
  - \*MAT\_079 – Nonlinear inelastic material model to capture relatively large energy dissipation in soil adjacent to structures
- Demonstrate that MAT\_232 can reasonably match SHAKE 1D seismic response analysis results
- Demonstrate that MAT\_079 can absorb the same amount of energy as predicted by the theoretical solution at the element level

## Overview - Validation of Time Domain SSI Analysis



- Validation will be performed using a representative SSI model which consists of a deeply embedded simple structure.
- Perform a time domain LS-DYNA analysis (using \*MAT\_232 to model soil) and a frequency domain SASSI analysis to demonstrate that seismic responses of the structure (when bonded with the soil) predicted by the two methods are similar
- Define the contact interface between the embedded structure and the soil and reperform the LS-DYNA SSI analysis. Show the difference between the results obtained from the two methods due to the geometric nonlinearity in the LS-DYNA model as the seismic intensity increases

## Progress – 1D Soil Seismic Response Analysis

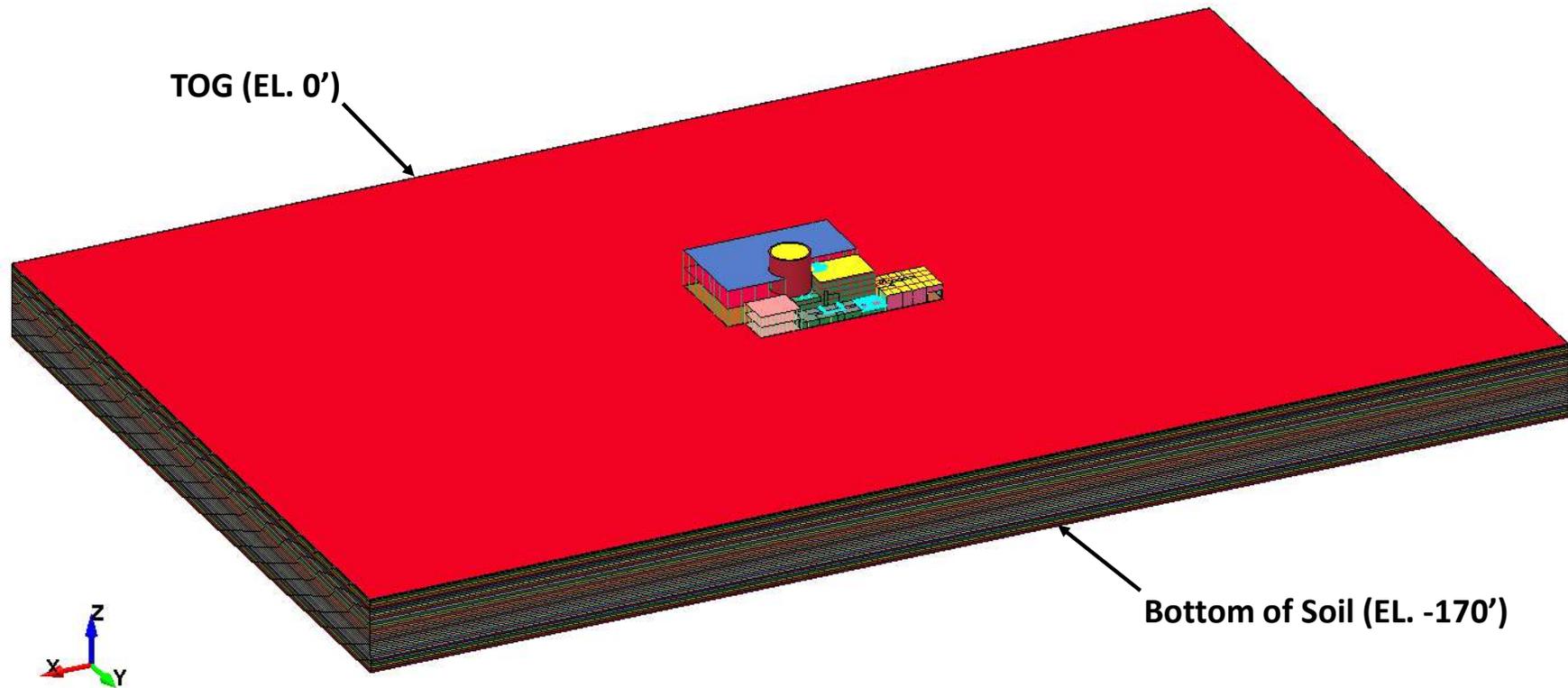


- Seven sets of input acceleration time histories have been developed according to the Holtec SMR seismic design response spectra and used for the SHAKE 1D seismic response analysis
- SHAKE 1D analyses have been completed to obtain strain compatible soil properties (modulus and damping ratio) for the LB, BE and UB soil profiles
- Bedrock elevation (-170') acceleration time histories in three directions obtained from SHAKE analysis will be used as the seismic input of the time domain LS-DYNA SSI analysis

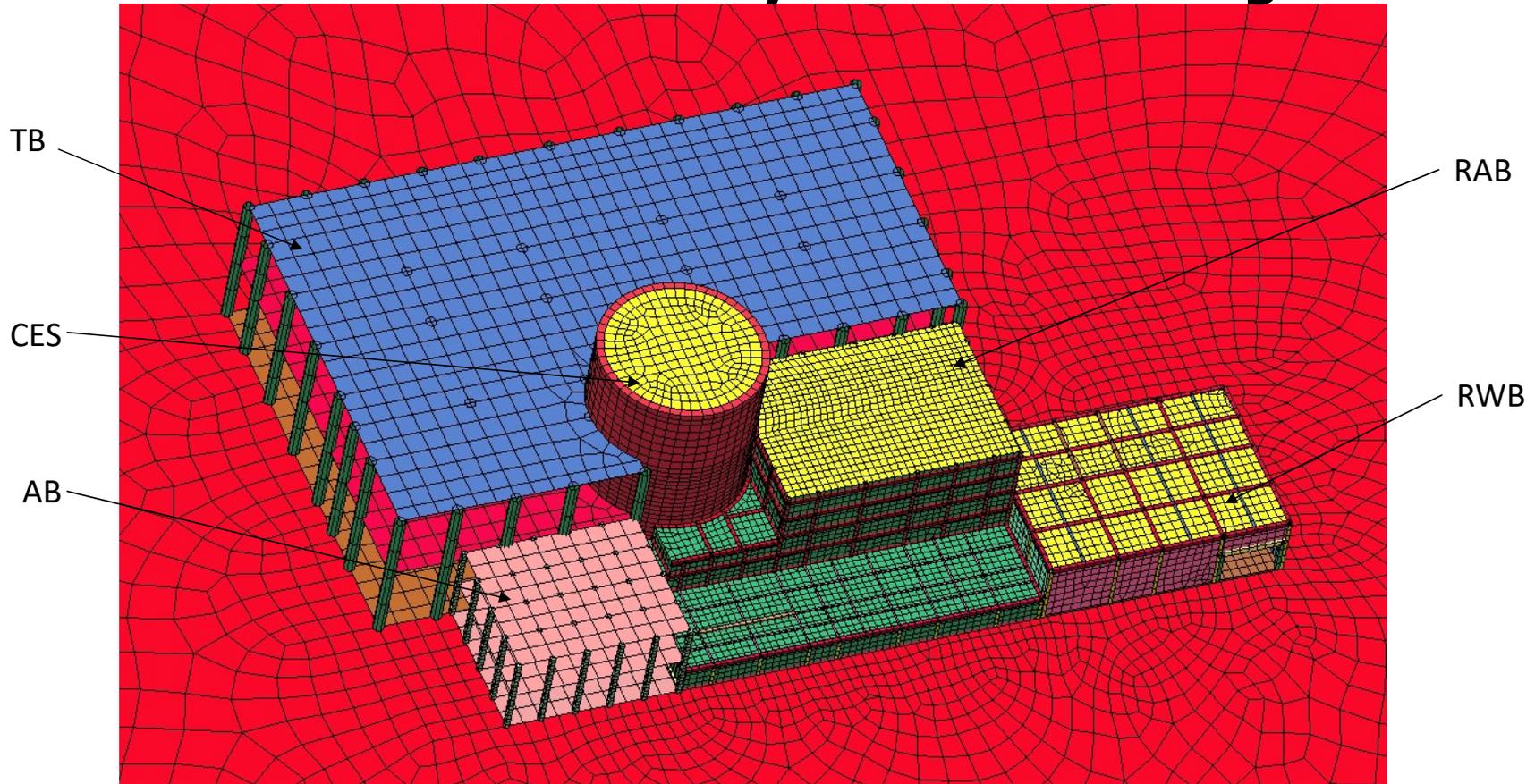
## **Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design**

- The LS-DYNA SSI model consists of soil, seismic structures, and adjacent non-seismic structures. These structures are CES (including CS, CS Internal structures), RAB, CB, RWB, TB and AB.
- Solid elements are used to model soil and thick civil structure components (e.g., basemats), as well as water in the annular reservoir and in the spent fuel pool through a simple fluid material model
- Shell or thick shell elements are used to model walls and slabs of civil structures or thin steel equipment/structures.
- Beam elements are used to model beams and columns of civil or steel structures and certain equipment
- Mass elements are used to account for the masses of equipment of significant weight

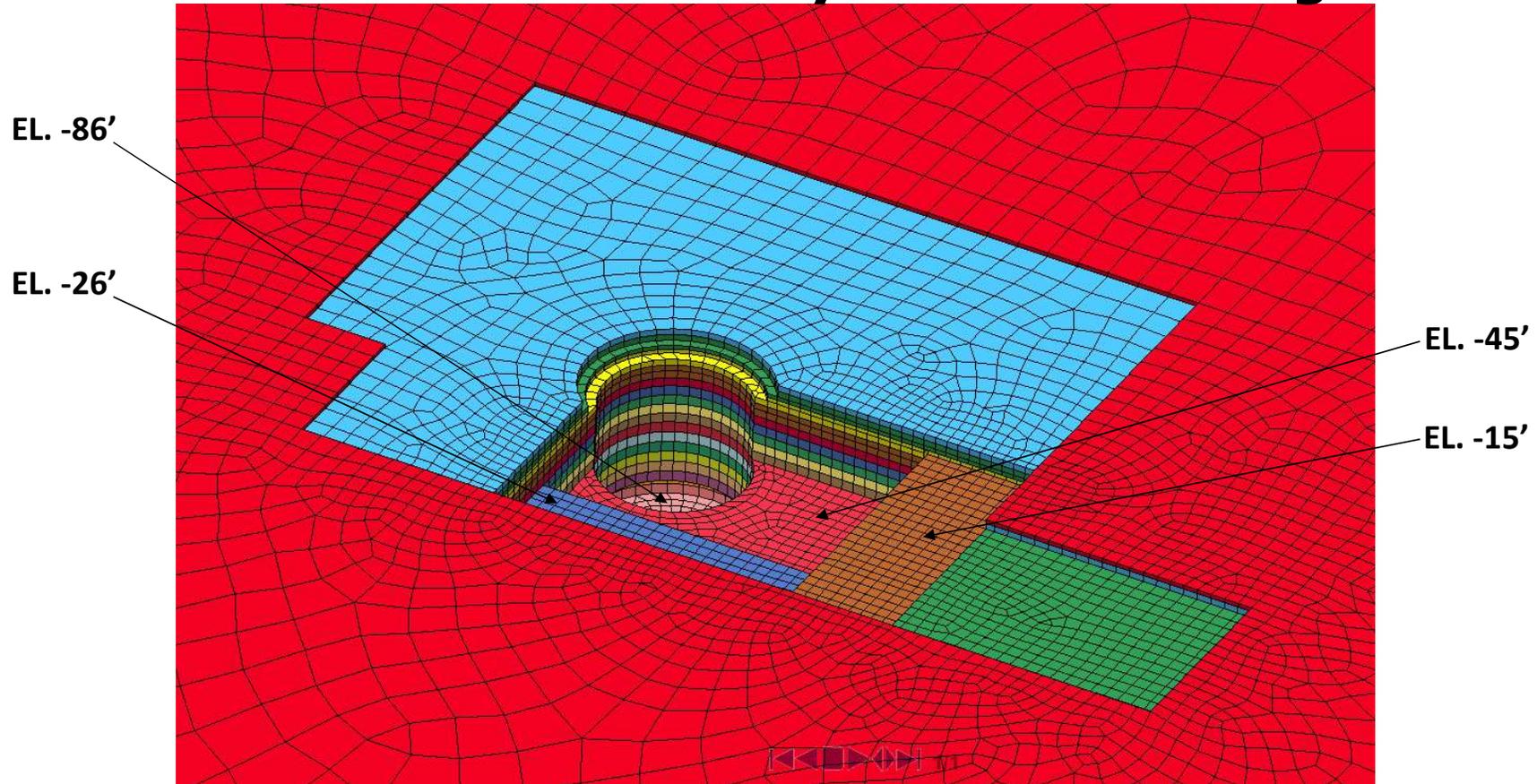
# Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design



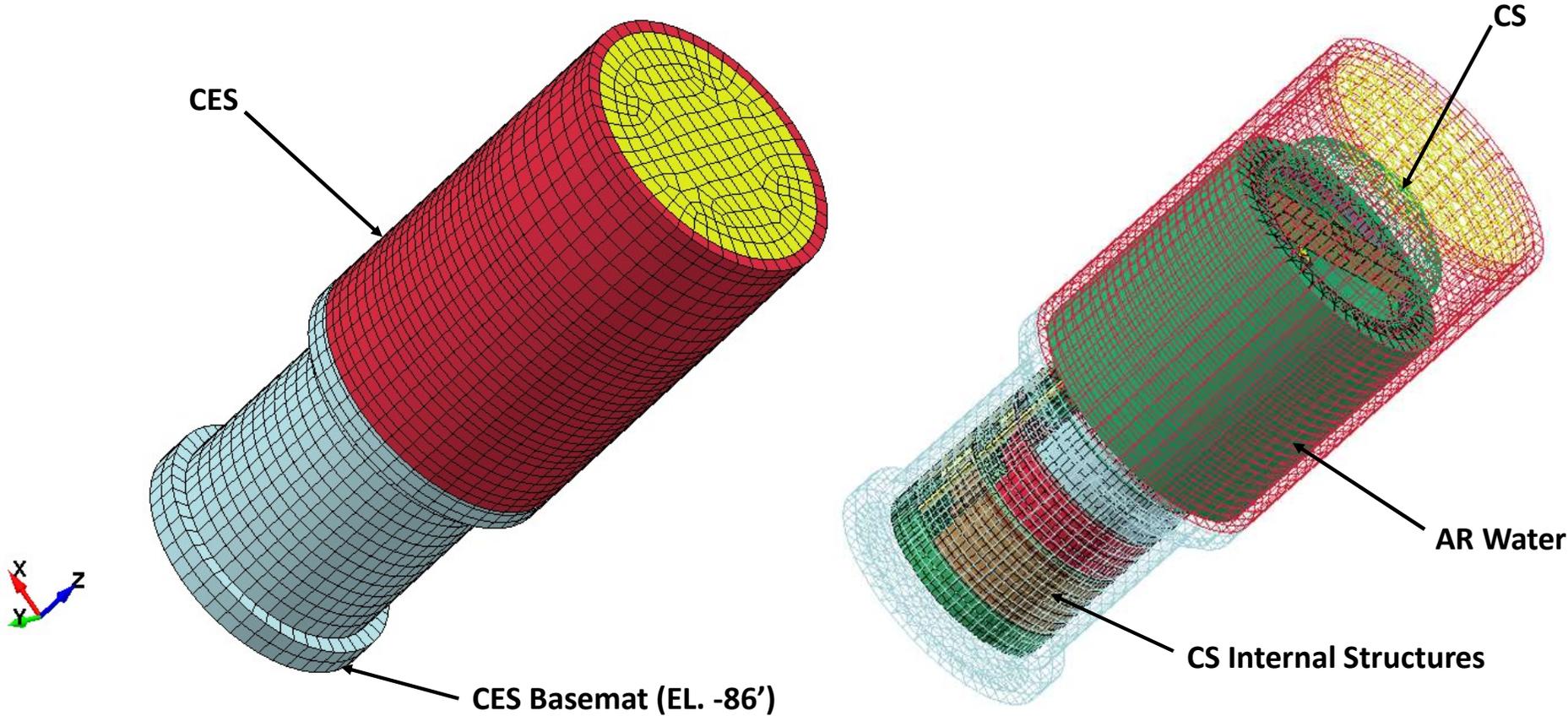
# Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design



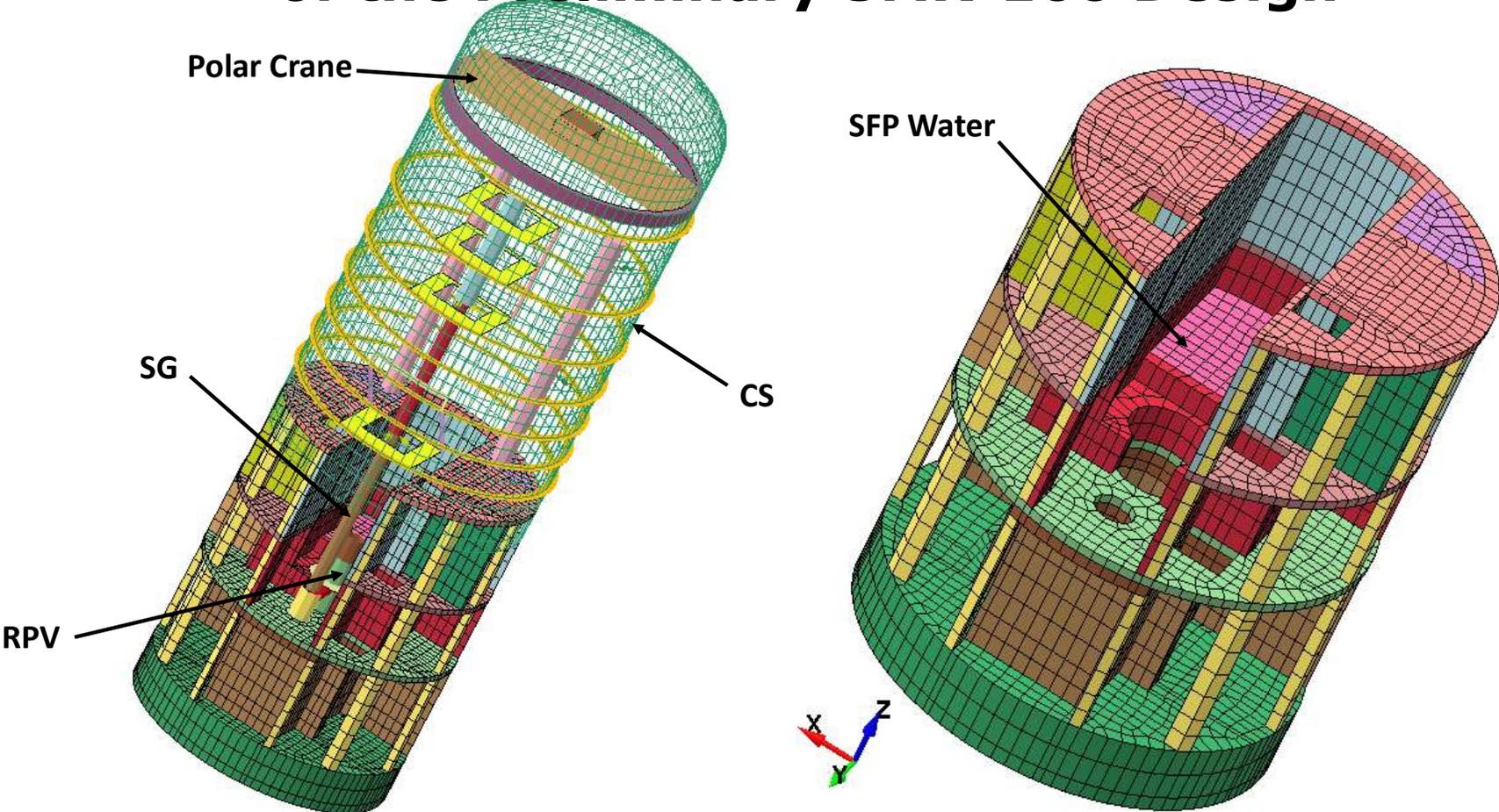
# Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design



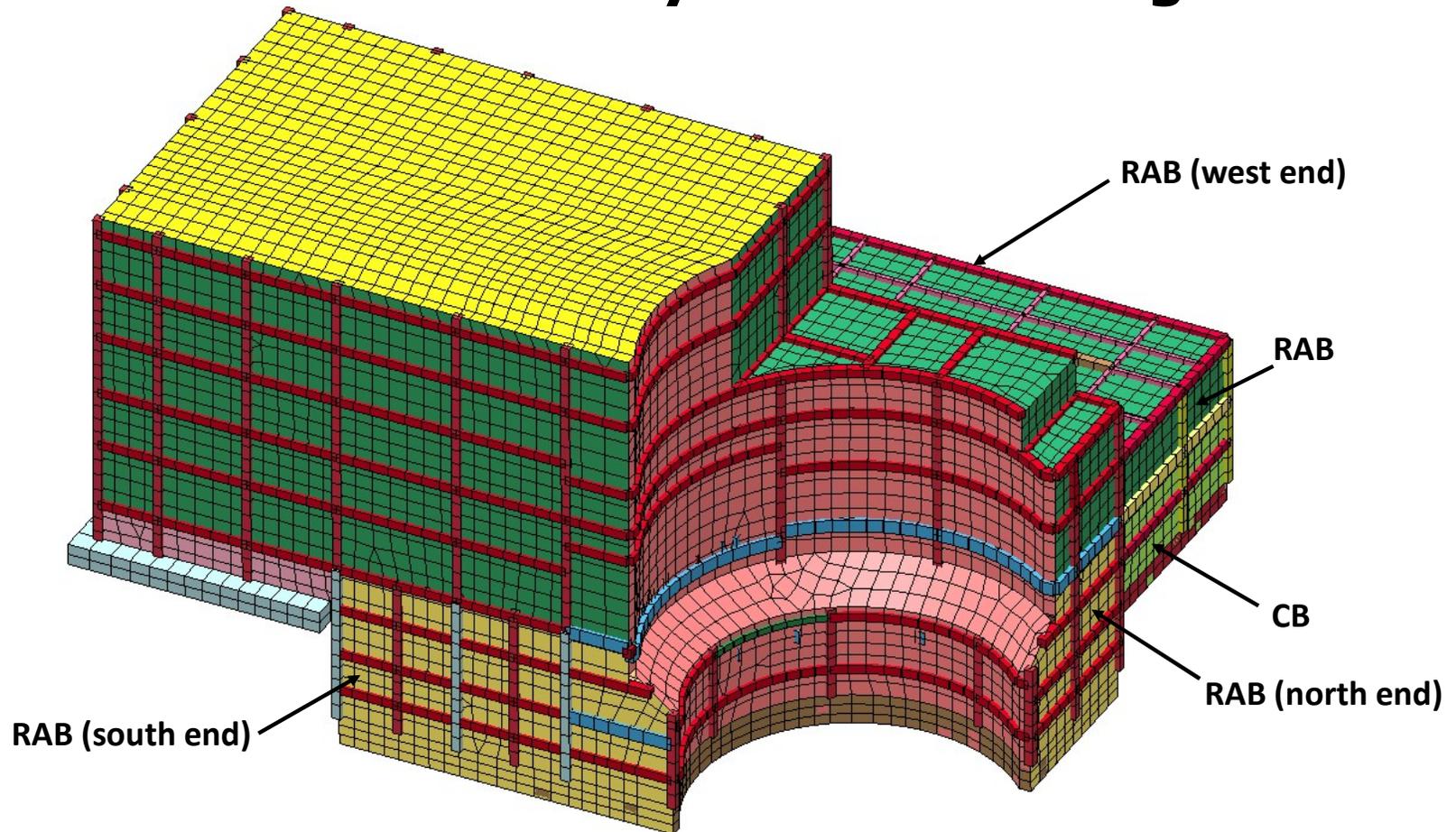
# Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design



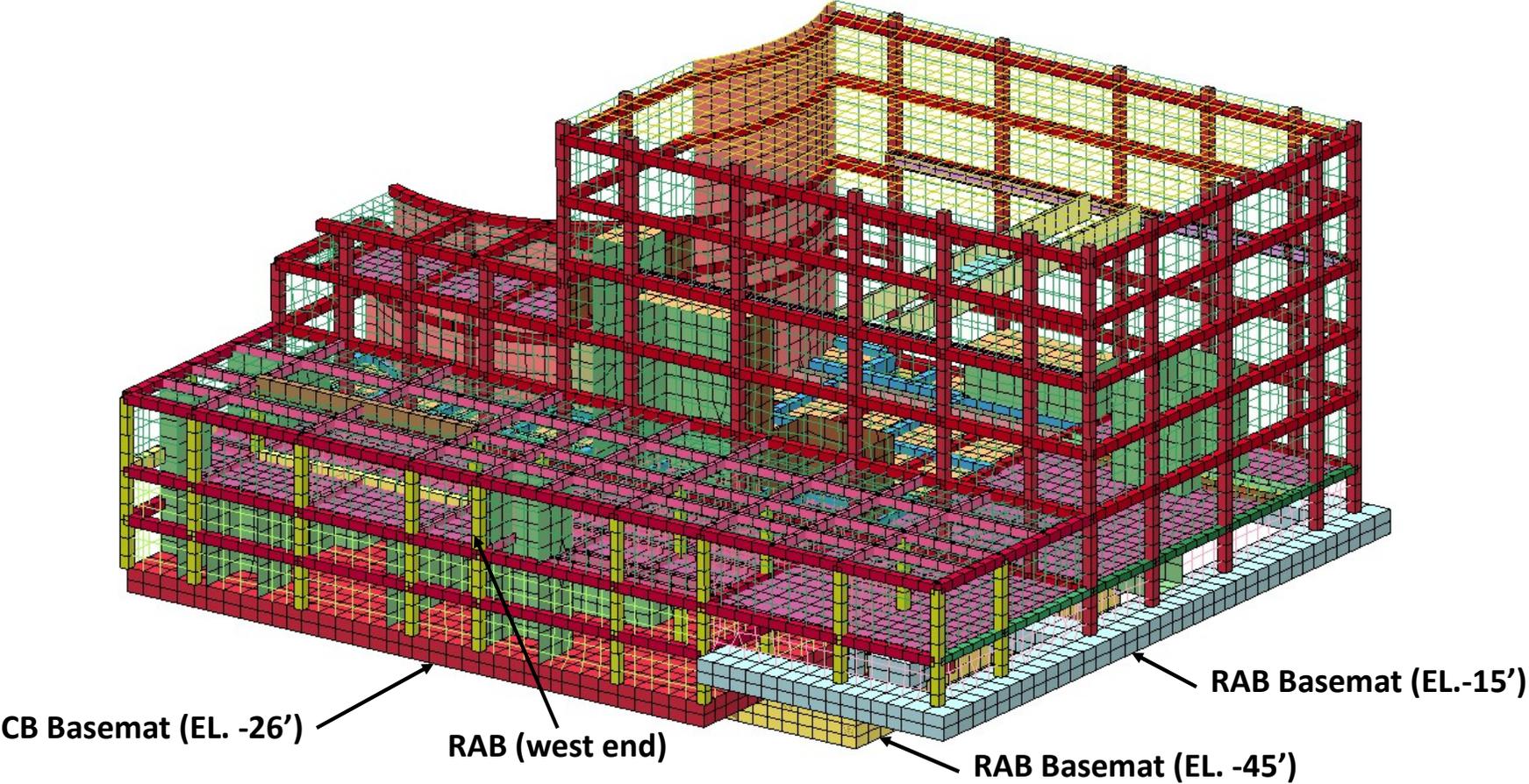
# Progress – LS-DYNA SSI Model Development of the Preliminary SMR-160 Design



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# Progress – Benchmarking of Soil Models

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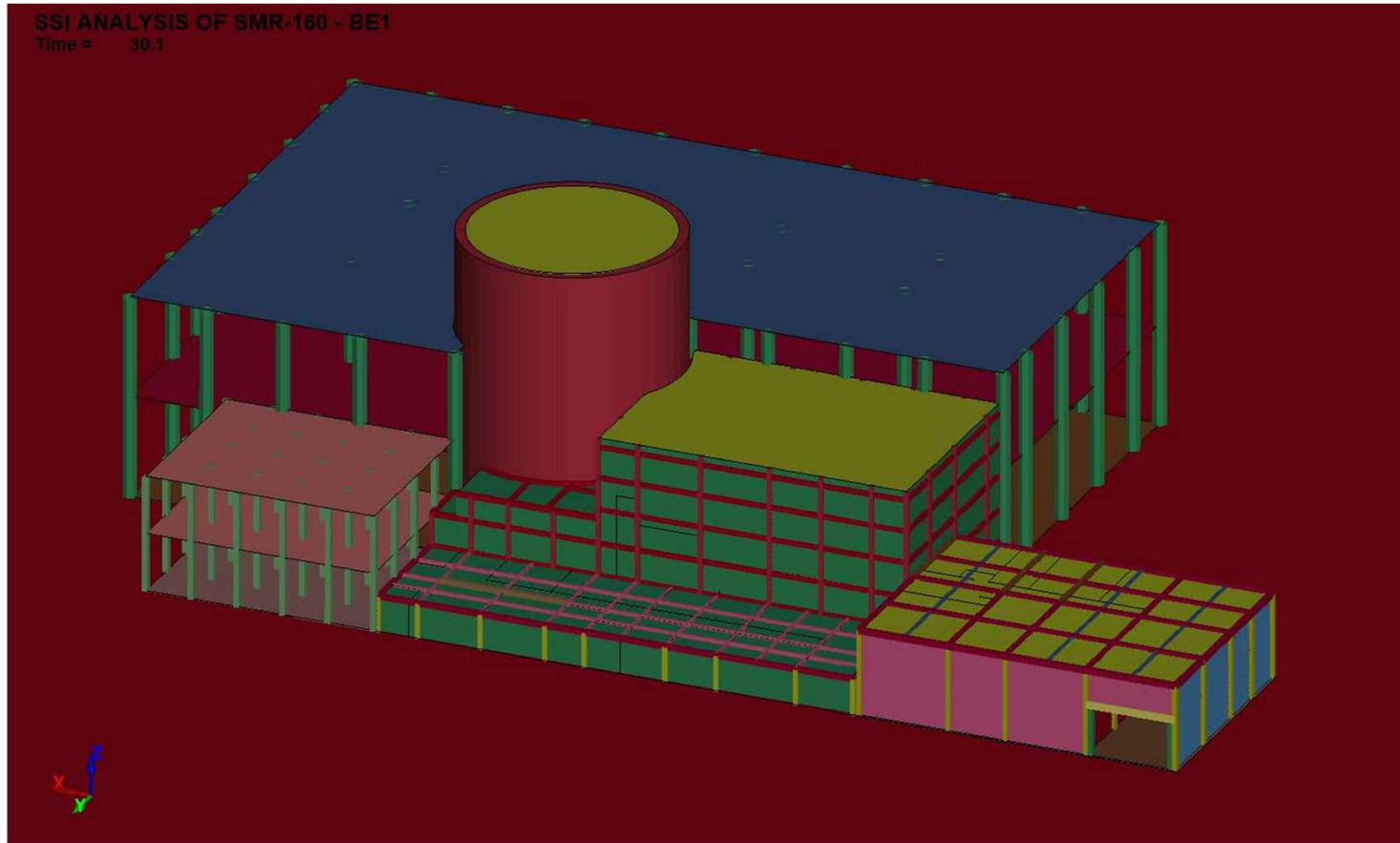
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# Progress – Benchmarking of Soil Models

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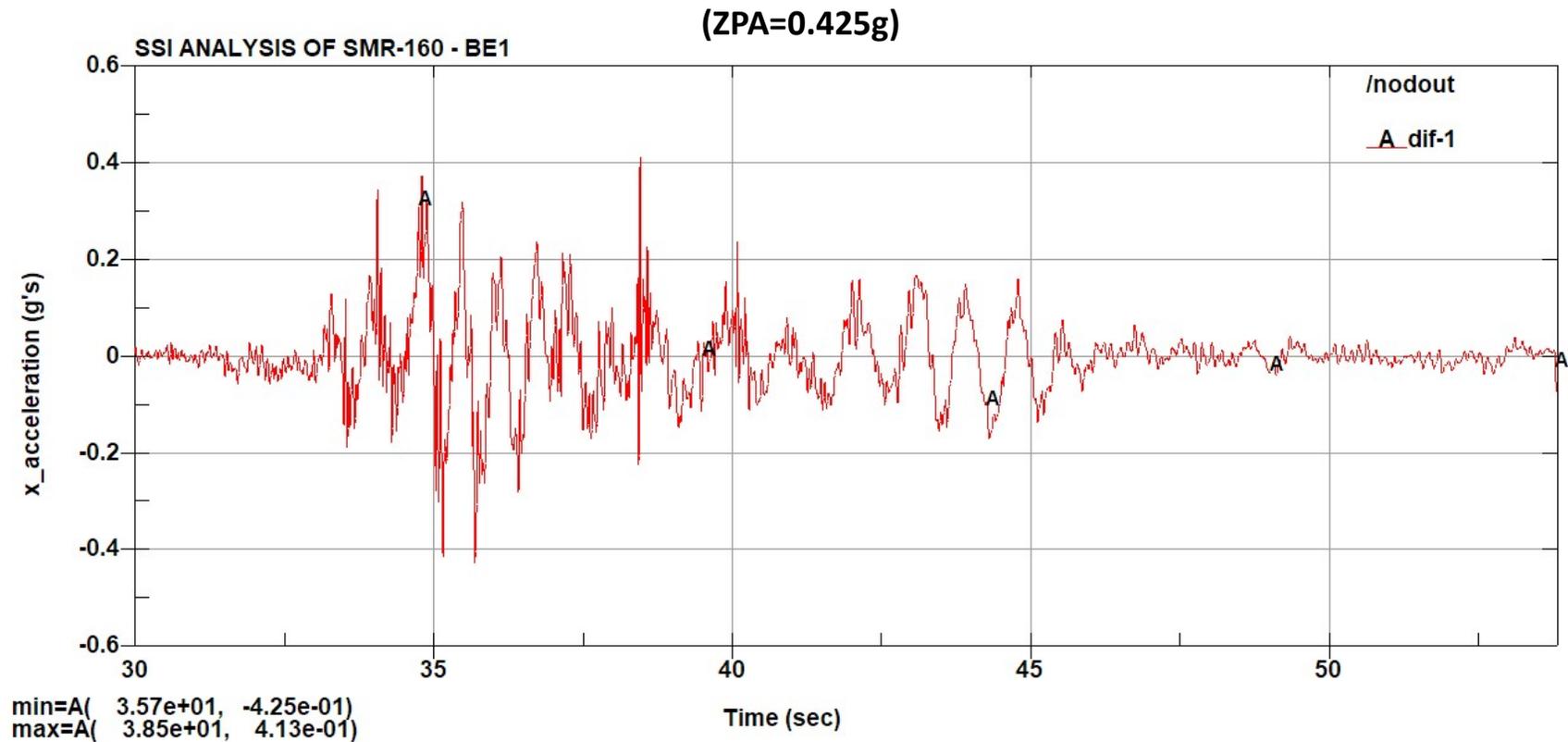
# Progress – Preliminary Analysis Results



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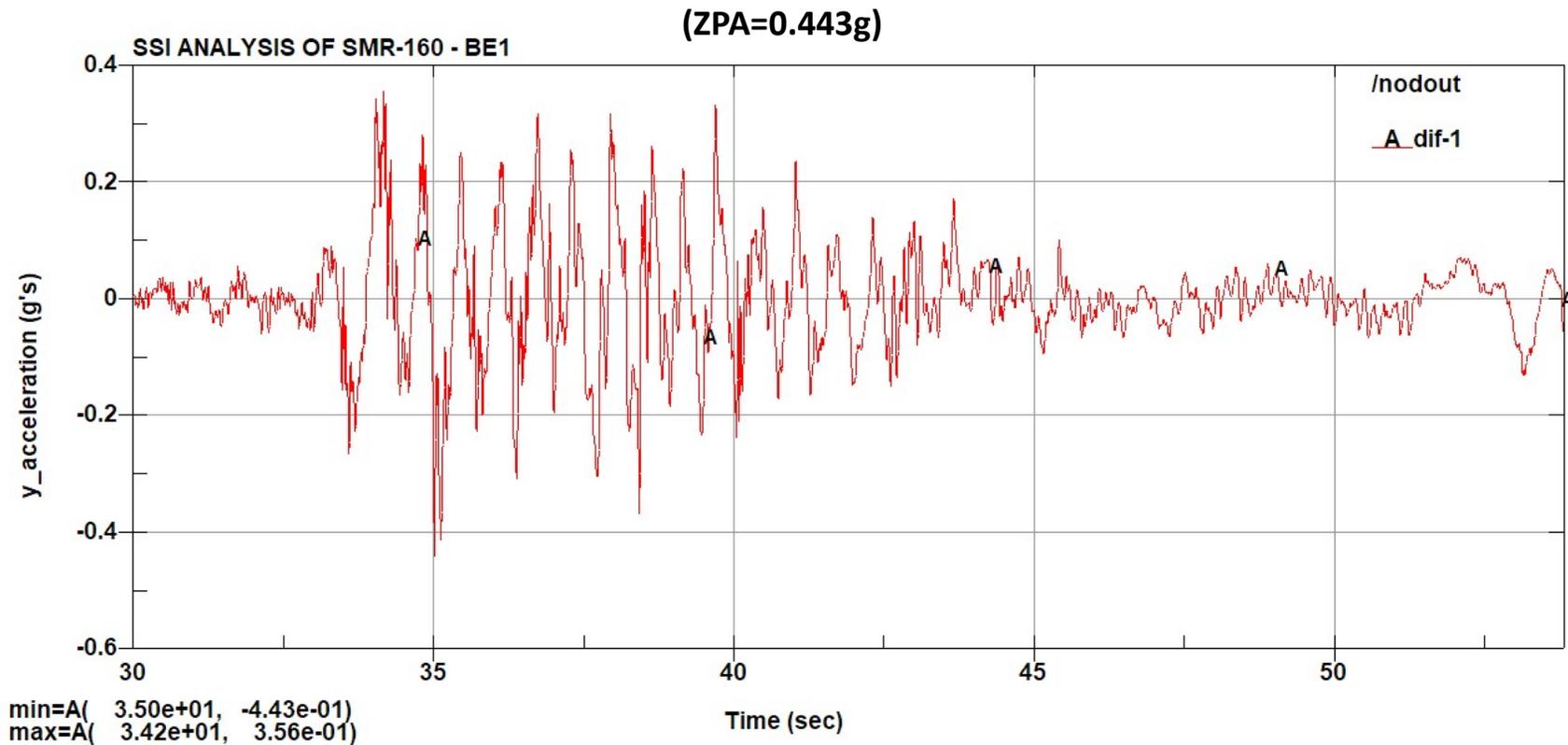
- Containment internal structure EL. 0' floor RPV stand acceleration time history – x dir.



# Progress – Preliminary Analysis Results



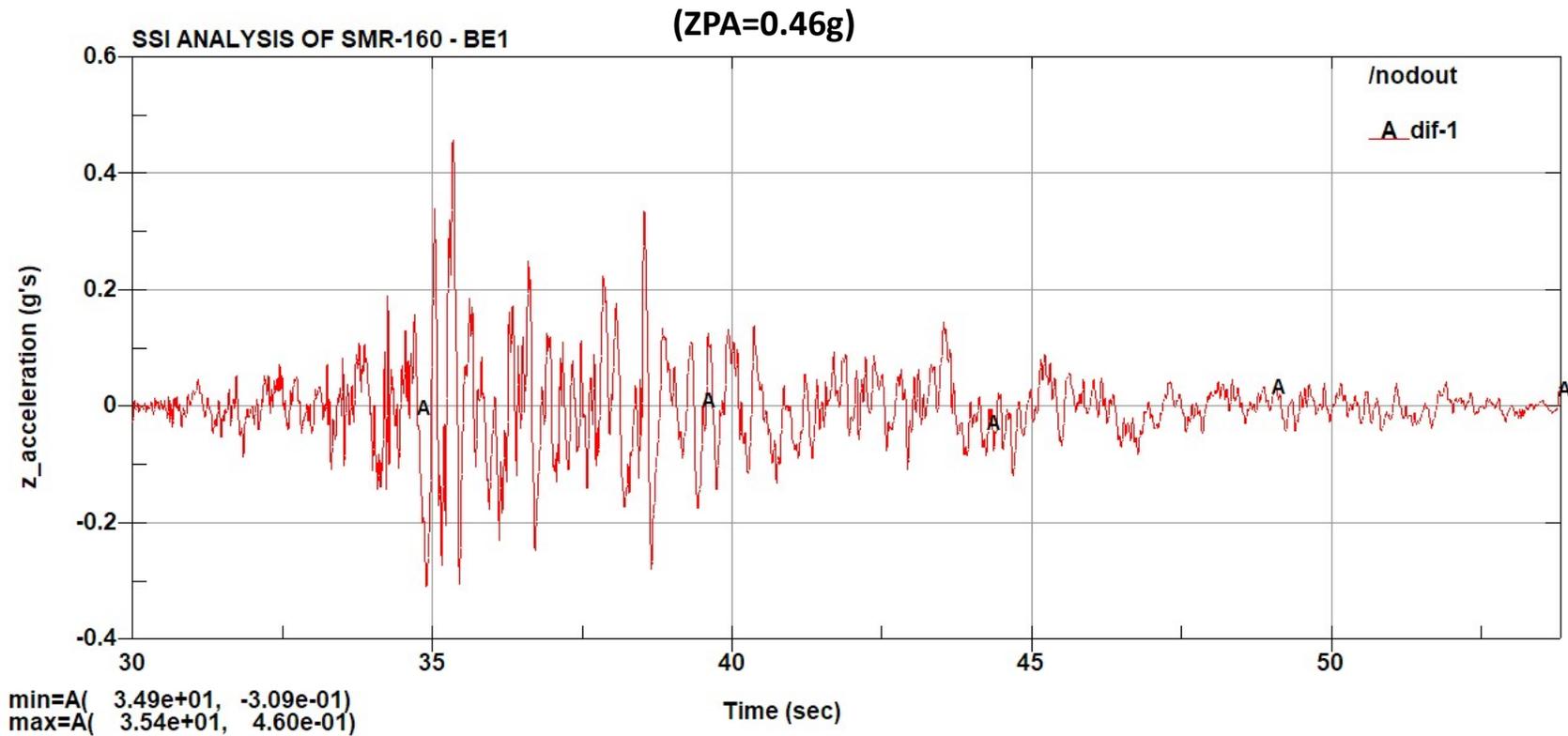
- Containment internal structure EL. 0' floor RPV stand acceleration time history – y dir.



# Progress – Preliminary Analysis Results



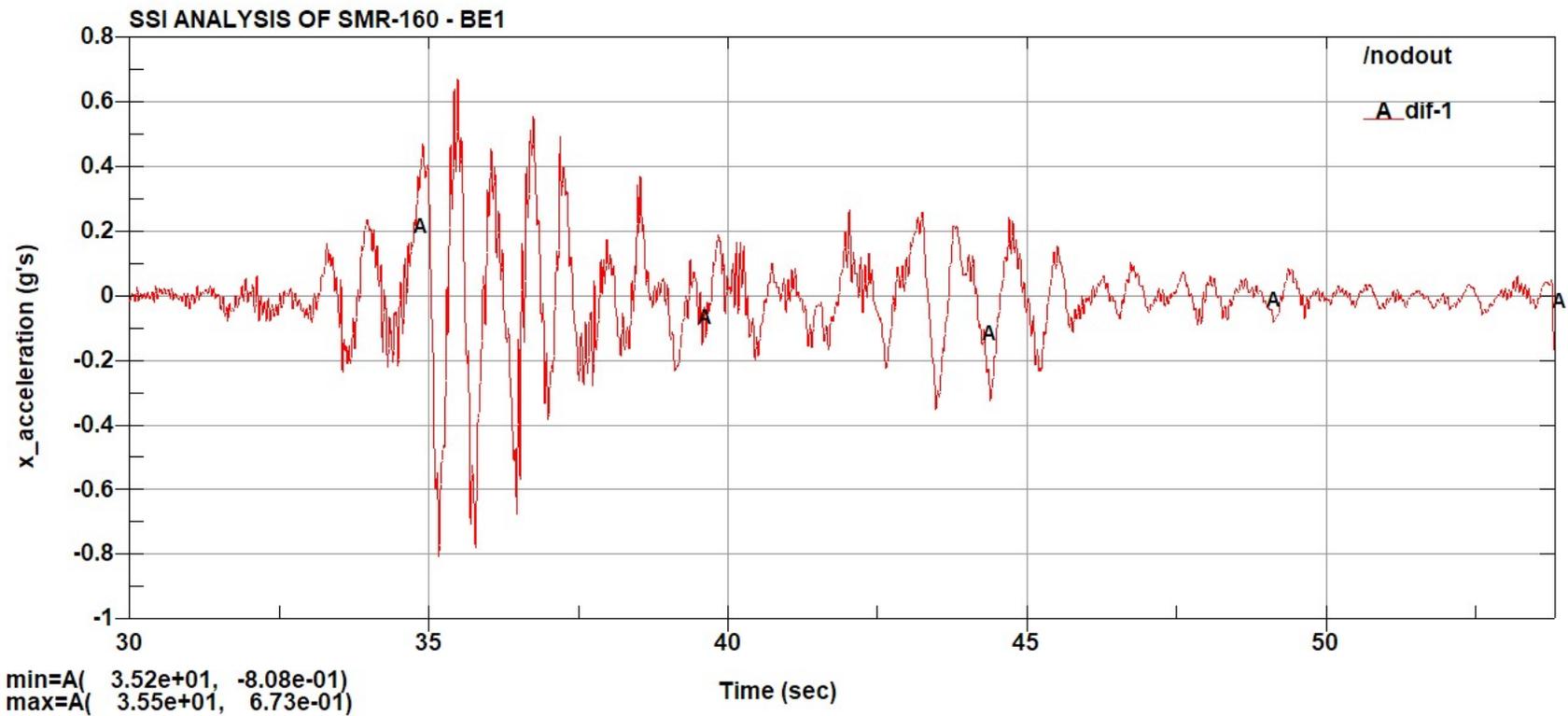
- Containment internal structure EL. 0' floor RPV stand acceleration time history – z dir.



# Progress – Preliminary Analysis Results



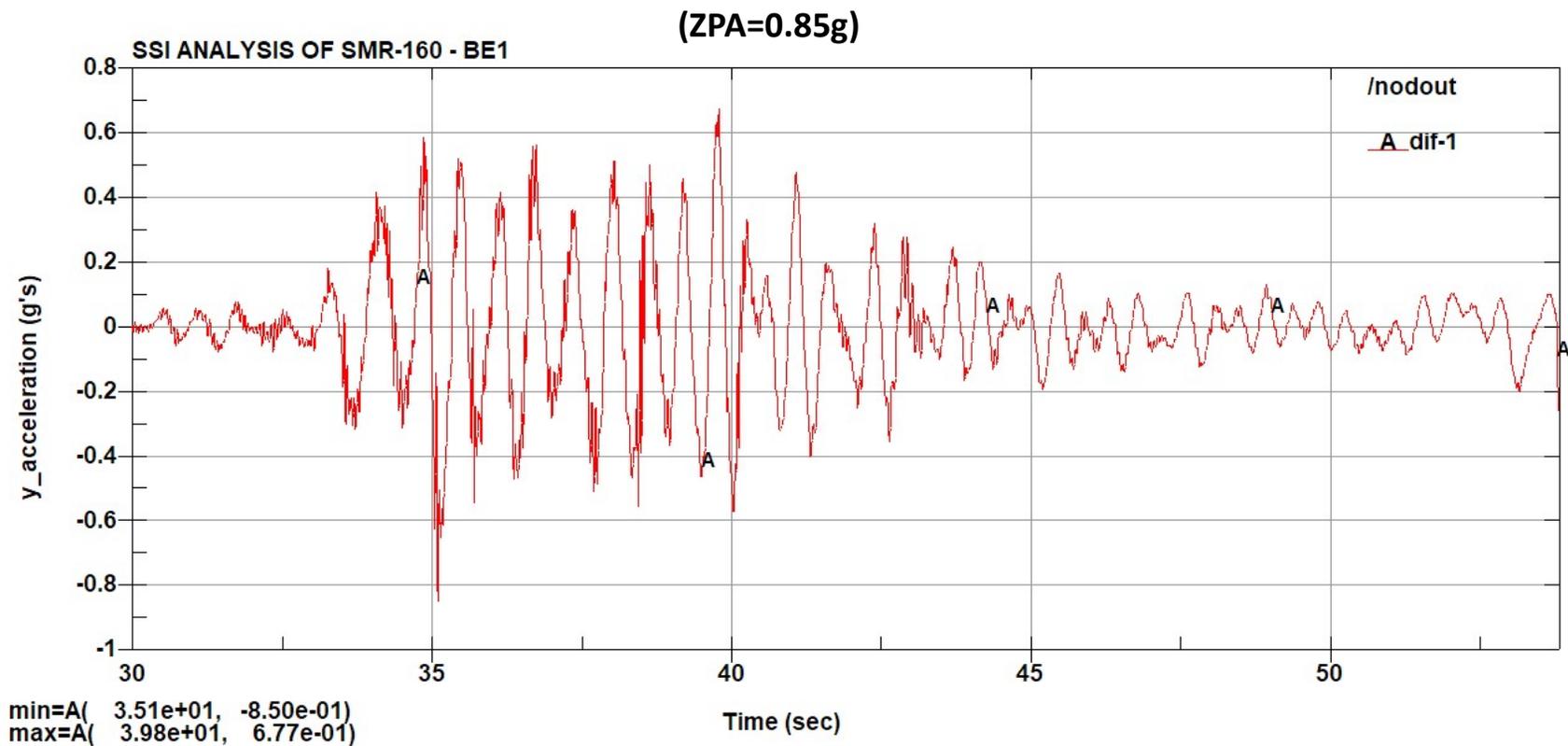
- Polar crane support (attached to the CS at EL. 81'-4") acceleration time history – x dir.  
(ZPA=0.808g)



# Progress – Preliminary Analysis Results



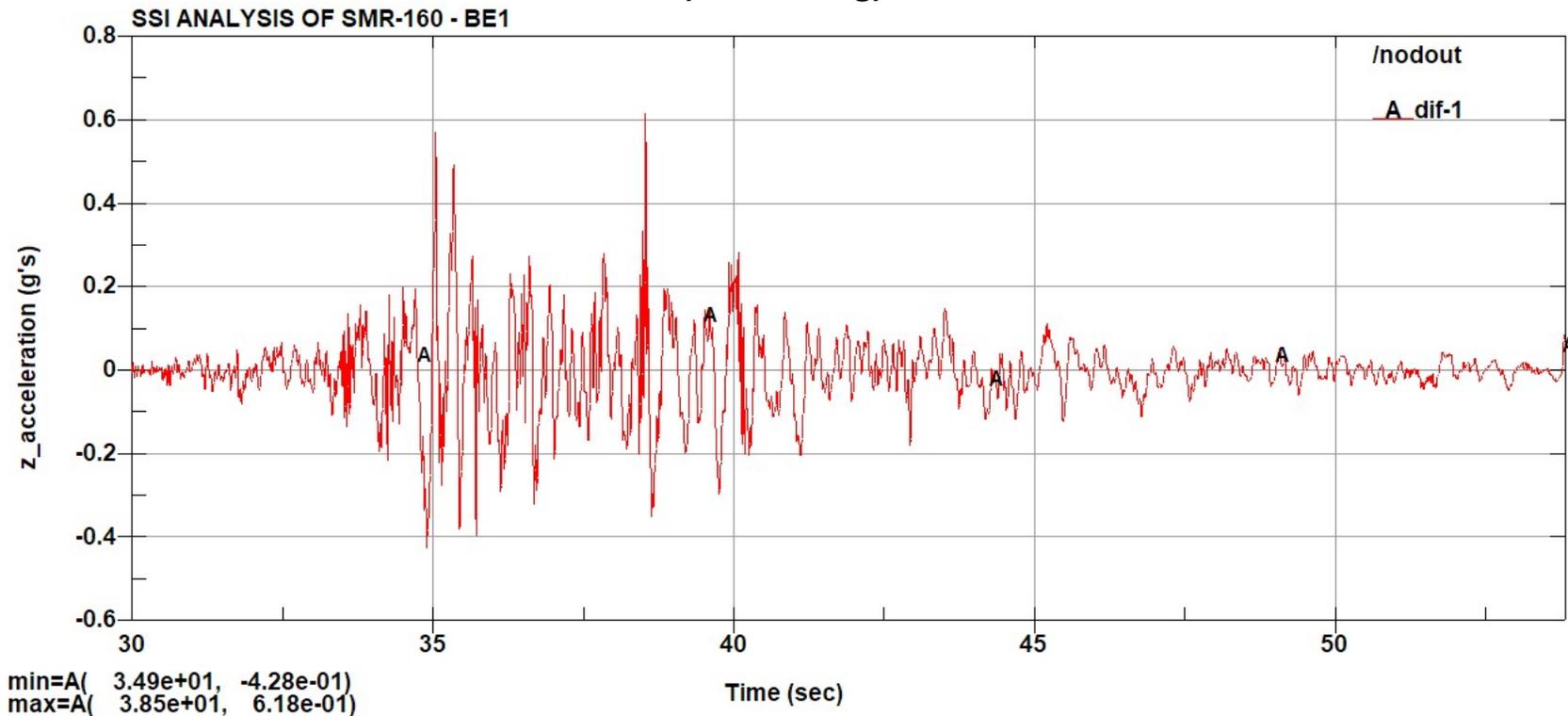
- Polar crane support (attached to the CS at EL. 81'-4") acceleration time history – y dir.



# Progress – Preliminary Analysis Results

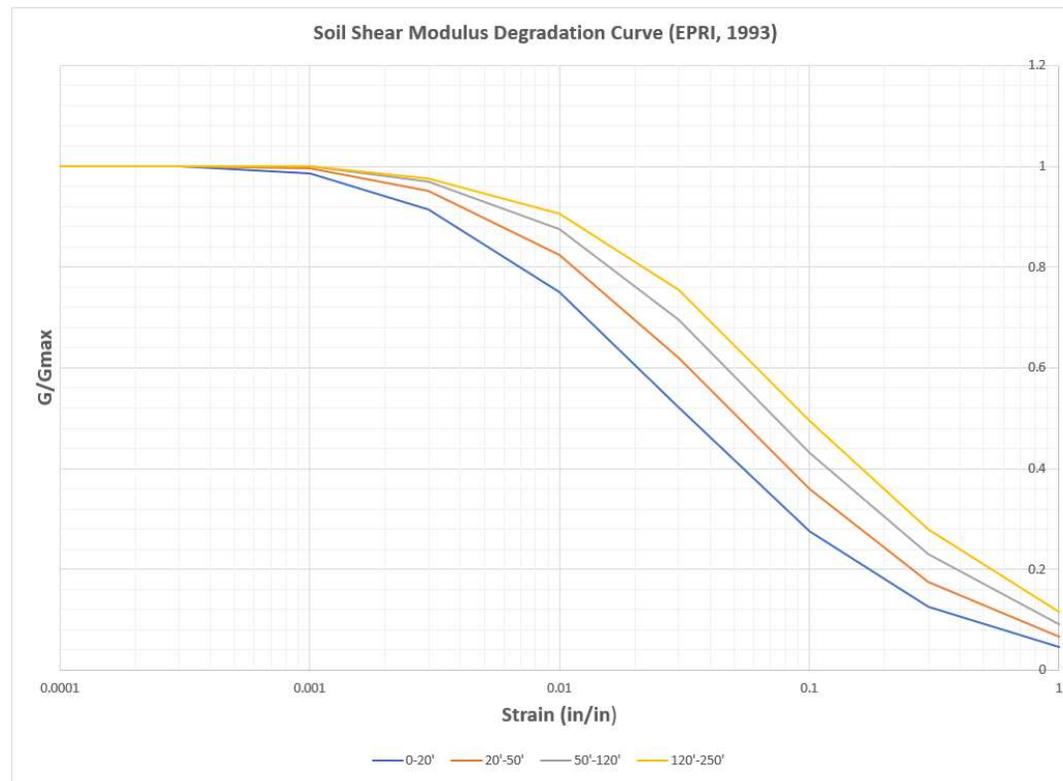


- Polar crane support (attached to the CS at EL. 81'-4") acceleration time history – z dir.  
(ZPA=0.618g)



# SSI Simulations

- Material model \*MAT\_079 will be used to simulate nonlinear soil behavior adjacent to embedded structures (strain > 0.35%).

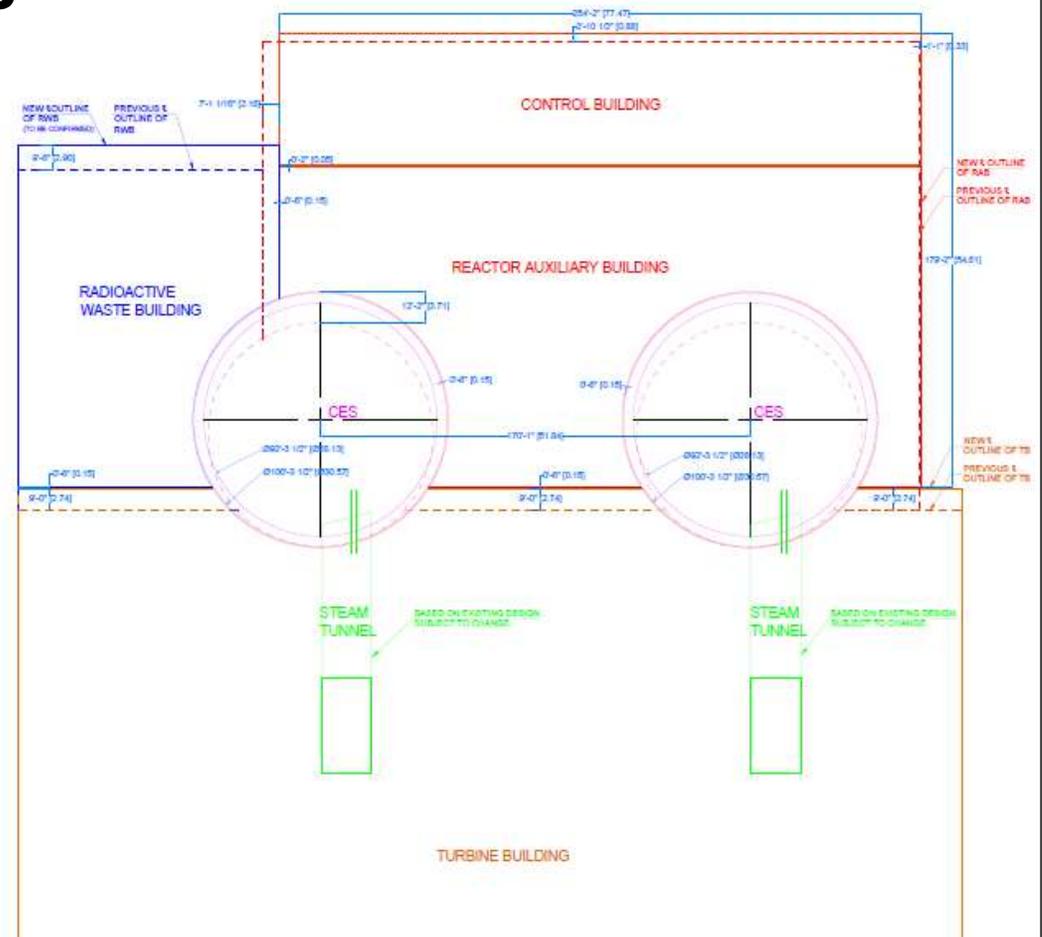


## SSI Simulations

- LS-DYNA SSI analyses will be performed for 3 soil profiles (LB, BE, and UB) and 7 earthquake sets.
  - ✓ The effects of concrete cracking in building structures and water table in soil will also be considered.
- Each SSI analysis is performed in two steps: (1) Applying gravity load only to initialize the stress/deformation fields; (2) Restarting the run with transient seismic load
- SSI analysis results of the 7 earthquakes are averaged for each of the analyzed configurations.
- ISRS – Enveloping all averaged response results and then smoothing and broadening per RG 1.122 and SRP 3.7.2

# Holtec SMR Updated Design

■ Holtec SMR design will replace the preliminary SMR-160 design as an updated plant design. SSI model will be updated accordingly.



## Licensing Approach

- Holtec is considering submitting a licensing topical report that includes both the SSI methodology and results using generic inputs that are intended to bound a number of potential soil sites in the United States, including the Palisades site.
- Additional soil/rock generic input parameters are also being considered for inclusion in the licensing topical report
- The licensing topical report is currently planned for mid 2025, and is intended to be referenced in a future CPA for SMRs at Palisades.

# Technical Questions

## ■ Multi-Unit Sites

- ✓ What is the minimum required separation distance between adjacent SMR sites for the individual site installations to be considered decoupled, e.g., greater than depth to bedrock?
- ✓ Is there any NRC guidance or accepted industry standard regarding structure-soil-structure interaction?

## ■ Water Table

- ✓ What level of analysis is required with respect to water table elevation, e.g., best estimate only?
- ✓ Is there any NRC guidance or accepted industry standard regarding effects of water table on SSI analysis?