SMR, LLC. A Holtec International Company
Krishna P. Singh Technology Campus,1 Holtec Blvd., Camden, NJ 08104
Telephone (856) 797-0900
Fax (856) 797-0909

September 23, 2022

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, DC 20555-0001

Subject: SMR, LLC Preapplication Meeting Materials for September 27, 2022 (Project No. 99902049)

SMR, LLC is pleased to submit presentation materials and supporting documentation for a preapplication meeting on September 27, 2022, regarding the seismic analysis methodology that will be used to support the construction permit application for the SMR-160 design. Enclosure 1 contains the presentation.

SMR, LLC has estimated approximately 10 hours for the review of this material by the NRC staff. If more hours are required for the review, please discuss with the SMR, LLC Director of Licensing. If you have any questions or require any additional information, please contact Justin Hawkins, SMR-160 Director of Licensing, at j.hawkins@holtec.com, (O) 856-797-0900 x3452, or (C) 609-941-5765.

Respectfully,

Justin Hawkins

Justin Hawkins
Director of Licensing, SMR, LLC

Enclosures:

1. SMR, LLC Meeting Presentation Materials for September 27, 2022 (NP)

CC:
T. Marcille (SMR, LLC, Vice President of Reactor Technologies)
J. Fleming (Holtec International, LLC, VP of Licensing, Regulatory Affairs & PSA)
R. Trotta (SMR, LLC, Director of SMR-160)
M. Dudek (USNRC, DNRL, NRLB, Branch Chief)
C. Lauron (USNRC, DRNL, NRLB, Senior Project Manager
G. Cranston (USNRC, DRNL, NRLB, Senior Project Manager)

Proposed SMR-160 SSI Analysis Method:
Time-Domain Nonlinear SSI Analysis Using A Hysteretic Soil Model

September 27, 2022

Overview

- Current Regulatory Guidance
- Typical SSI Time History Analysis Methods
- Proposed SSI Analysis Method for SMR-160
- Validation of the Time-Domain Analysis Method
- SMR-160 Seismic Design Parameters
- Nonlinearities of Soil
- Validation of Soil Model *MAT_079
- Questions

Current Regulatory Guidance

- NUREG-0800 SRP 3.7.2 (Seismic System Analysis)
  - Truly nonlinear analysis is not required unless the comparison of results indicate deficiencies that cannot be accounted for. Acceptance criteria generally deal with linear elastic analysis. However, the staff has accepted the consideration of limited inelastic/nonlinear behavior for certain special cases (e.g., stability and as-built structure analyses).
  - Sensitivity studies are required to identify potential uplift, separation and sliding using well-founded & properly substantiated simple models to give better insight.
  - If nonlinear analysis method is used, results should be judged on the basis of the linear or equivalent linear analysis (NUREG/CP-0054).
  - Acceptable Seismic Analysis Methods for seismic Category I SSCs:
    - Response spectrum analysis method
    - Time history analysis method
    - Equivalent static load analysis method

Typical SSI Time History Analysis Methods

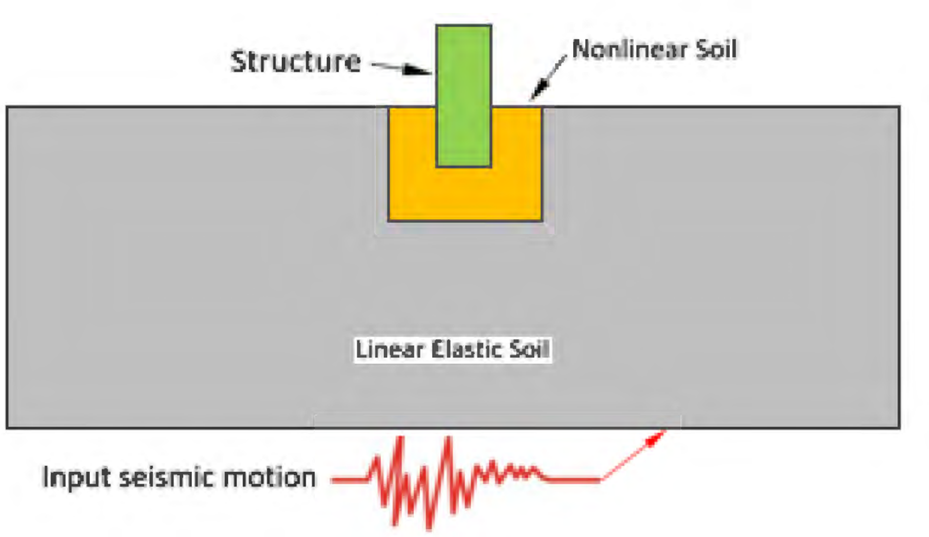
- SSI Time History Analysis Method
  - Frequency Domain:
    - Complex frequency response (transfer function) method
      - SASSI
    - Modal superposition method
      - ANSYS
    - Pros: computationally efficient;
    - Cons: no nonlinearities, accuracy depends on # of frequencies
  - Time Domain:
    - Linear analysis
      - LS-DYNA – same SSI analysis results as SASSI for low intensity earthquakes
    - Nonlinear analysis
      - LS-DYNA – accurate for cases with material/geometric nonlinearities

Proposed SSI Analysis Method for SMR-160

- Why time-domain nonlinear analysis?
  - Linear SSI analysis in frequency domain is not suitable when any of the following behaviors are expected to be important:
    - Sliding & gapping at structure/soil interface (geometric nonlinearity)
    - Permanent soil deformation and local soil failure
    - Nonlinear coupling of soil and pore fluid
  - At high shear strain levels, the equivalent linear soil model used in SASSI overstates resonances in response spectra and understates the ability of the soil to pass high frequencies to the structure.
  - Nonlinear analyses are widely used in building and bridge industries
  - ASCE 4-2016 adds Appendix B that provides guidance for nonlinear time domain SSI analysis

Proposed SSI Analysis Method for SMR-160

- Proposed SSI model



  - Nonlinear soil model is used locally in the relatively large strain region where SSI effect is strong
  - Overall soil response is modeled by equivalent linear elastic model (strain compatible modulus and damping) from SHAKE analysis

Proposed SSI Analysis Method for SMR-160

- The SSI model includes all seismic Category I & II buildings and the effects of nearby non-seismic buildings that are massive and could interact with seismic buildings during an earthquake.
- The input seismic motion is represented by 7 sets of acceleration time histories that are developed based on the SMR-160 seismic design responses spectra (SDRS), which are defined as the outcrop seismic motion at the containment enclosure structure (CES) basemat bottom elevation (EL -86’).
- Soil properties are defined by shear wave velocity profiles closely following and enveloping the lower range and upper range profiles of typical nuclear power plant soil sites (Figure I-1 of NUREG/CR-6865). The LB, BE, and UB also satisfy SRP 3.7 with COV ≥ 1.

Validation of the Time-Domain Analysis Method

- Perform the following SSI analysis for a simplified structure/linear soil model using LS-DYNA and SASSI to demonstrate that seismic responses predicted by the two computer codes are very similar for small earthquake intensities:
    - ❑ Perform an SSI analysis for a deeply embedded structure (e.g., the SMR-160 Containment Enclosure Structure embedded 86’ below grade)
- Repeat the above SSI analyses for a strong earthquake condition and show increased differences between the results obtained from the two codes due to geometric nonlinearity (contact interfaces) considered in the LS-DYNA SSI analysis model.

SMR-160 Seismic Design Parameters

- Seismic Design Response Spectra (SDRS) at the CES foundation bottom elevation (EL -86')

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

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

SMR-160 Seismic Design Parameters

- Lower Bound Soil Parameters:

Layer No.	Thickness (ft)	Depth (ft)	Shear Wave Velocity (ft/s)	Density (pcf)	Poisson's Ratio
1	2	-2	600	120	0.35
2	3	-5	650	120	0.35
3	15	-20	700	120	0.35
4	20	-40	990	120	0.35
5	20	-60	1170	120	0.35
6	20	-80	1200	120	0.35
7	20	-100	1145	120	0.35
8	20	-120	1150	120	0.35
9	40	-160	1170	130	0.35
10	40	-200	1190	130	0.35
11	50	-250	1250	130	0.35
12	Half Space	-250	8000	150	0.25

SMR-160 Seismic Design Parameters

- Best Estimate Soil Parameters:

Layer No.	Thickness (ft)	Depth (ft)	Shear Wave Velocity (ft/s)	Density (pcf)	Poisson's Ratio
1	2	-2	900	120	0.35
2	3	-5	1000	120	0.35
3	15	-20	1150	120	0.35
4	20	-40	1410	120	0.35
5	20	-60	1660	120	0.35
6	20	-80	1697	120	0.35
7	20	-100	1700	120	0.35
8	20	-120	1725	120	0.35
9	40	-160	1770	130	0.35
10	40	-200	1840	130	0.35
11	50	-250	1920	130	0.35
12	Half Space	-250	8000	150	0.25

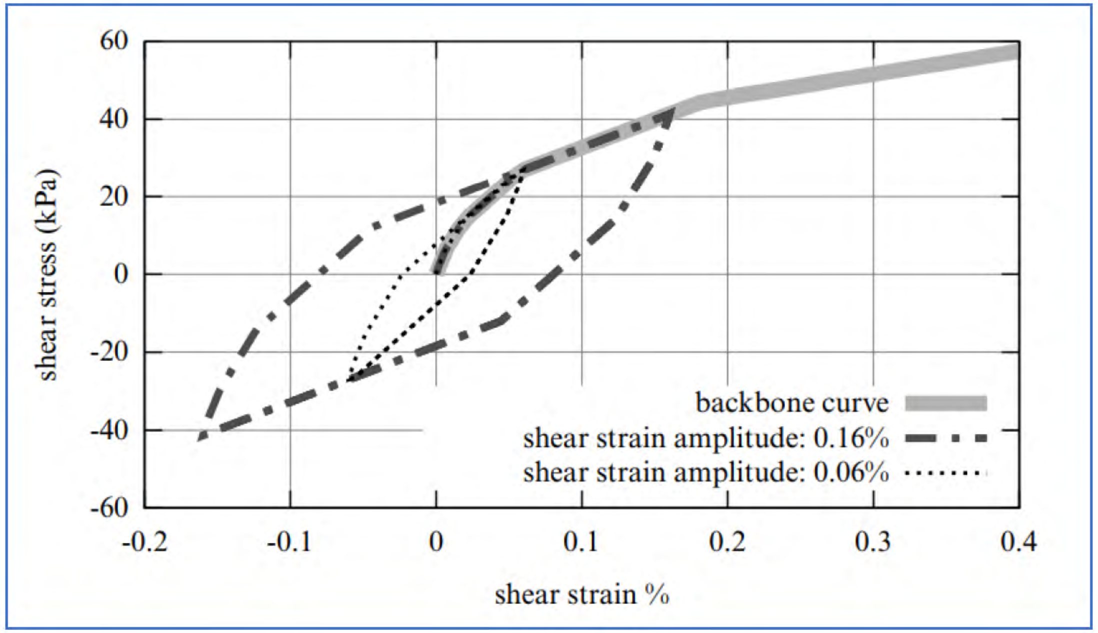
SMR-160 Seismic Design Parameters

- Upper Bound Soil Parameters:

Layer No.	Thickness (ft)	Depth (ft)	Shear Wave Velocity (ft/s)	Density (pcf)	Poisson's Ratio
1	2	-2	1300	120	0.35
2	3	-5	1450	120	0.35
3	15	-20	1690	120	0.35
4	20	-40	2000	120	0.35
5	20	-60	2350	120	0.35
6	20	-80	2400	120	0.35
7	20	-100	2410	120	0.35
8	20	-120	2450	120	0.35
9	40	-160	2550	130	0.35
10	40	-200	2670	130	0.35
11	50	-250	2780	130	0.35
12	Half Space	-250	8000	150	0.25

Nonlinearities of Soil

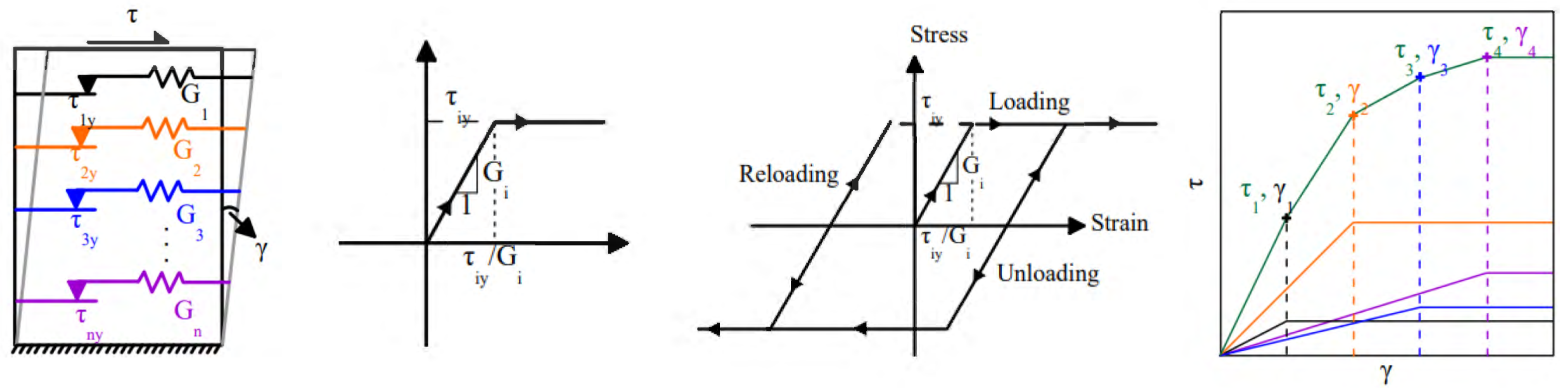
- Soil is a nonlinear material with hysteresis, where the loop area represents the energy absorbed by soil in a loading cycle



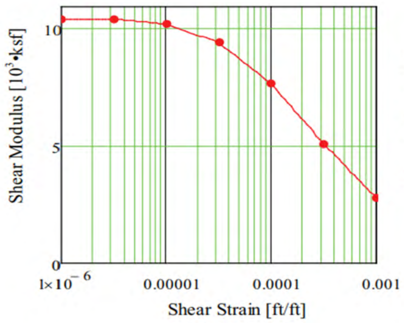
- Can be modeled by LS-DYNA material model *MAT_079, which will be validated through a two step (element level and 1-D seismic response) process

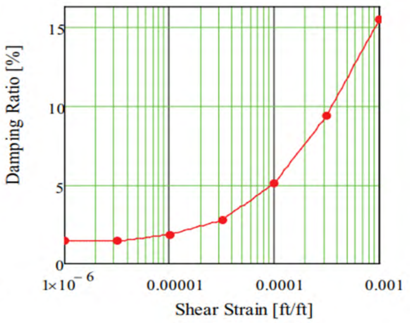
Validation of Soil Model *MAT_079

- *MAT_HYSTERETIC_SOIL (*MAT_079)
  - Each element has up to 20 spring-slider "layers" that are elastic perfectly plastic w/different elastic stiffness & yield strength values



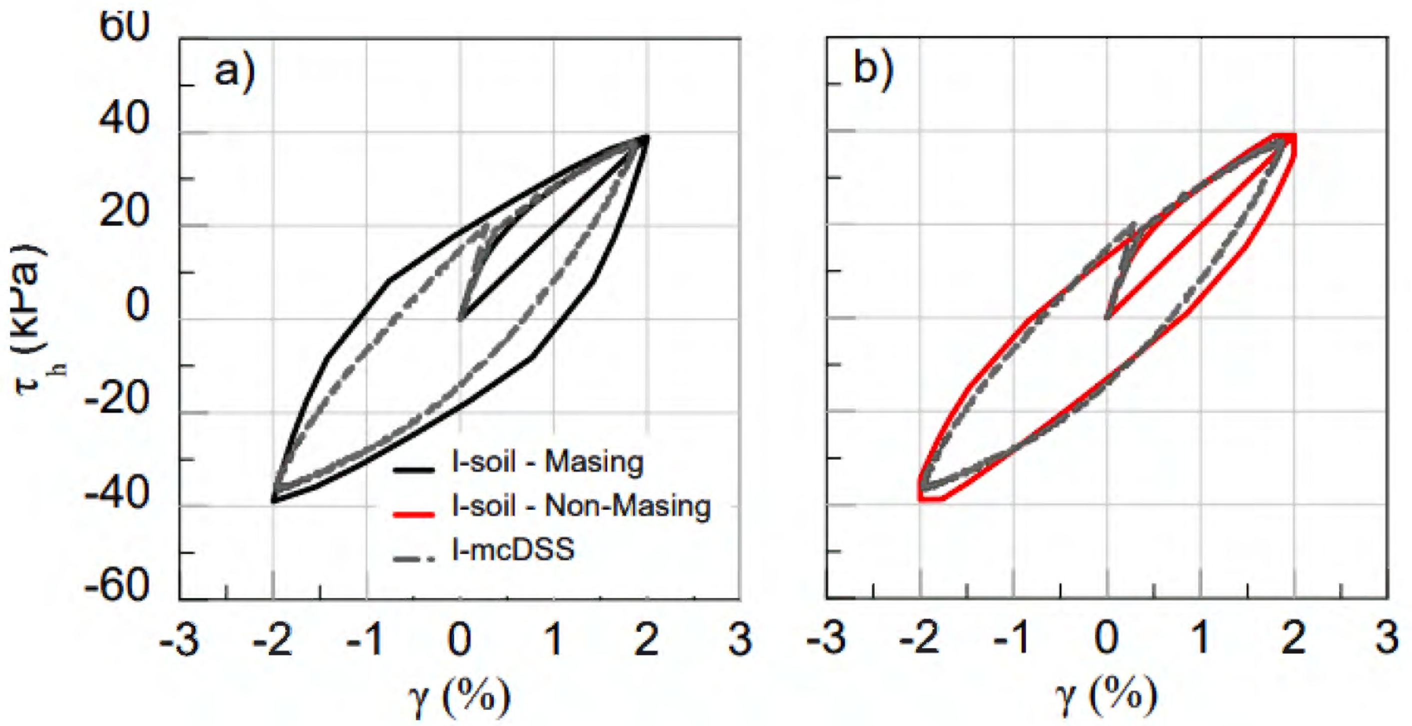
  - To be calibrated/validated per shear modulus & damping curves and show correct energy loss prediction in a single soil element





Validation of Soil Model *MAT_079

- Was validated in an NRC Technical Report (ML19178A190 prepared by UIUC, June 2019), which shows *MAT-079 model using the non-Masing damping option can accurately predict the soil hysteresis obtained from a strain controlled cyclic test



Validation of Soil Model *MAT_079

- Soil 1-D Seismic Response Validation
  - Develop an LS-DYNA 3-D FE model for the soil profile that has been analyzed for 1-D seismic response using SHAKE2000
  - Apply non-reflective boundary condition to the FE model bottom surface nodes and slaved boundary condition to the periphery surface nodes
  - Apply the seismic acceleration time history obtained from SHAKE2000 analysis at the soil column base to the FE model bottom surface nodes.
  - Perform the first LS-DYNA time history analysis by using the *MAT_079 material model with element level calibration/validation to characterize each type of soil considered in the soil profile
  - Perform the second LS-DYNA time history analysis by using the strain compatible soil properties obtained from the SHAKE2000 analysis to model all soils as a linear elastic material
  - Demonstrate that the obtained TOG response spectra obtained from the two LS-DYNA simulations reasonably match the SHAKE2000 prediction.

Questions?