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RAIO-0818-61556

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Docket No. 52-048

U.S. Nuclear Regulatory Commission
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SUBJECT: NuScale Power, LLC Supplemental Response to NRC Request for Additional Information No. 110 (eRAI No. 8932) on the NuScale Design Certification Application

REFERENCES:
1. U.S. Nuclear Regulatory Commission, "Request for Additional Information No. 110 (eRAI No. 8932)," dated July 30, 2017
2. NuScale Power, LLC Response to NRC "Request for Additional Information No. 110 (eRAI No.8932)," dated April 30, 2018
3. NuScale Power, LLC Response to NRC "Request for Additional Information No. 110 (eRAI No.8932)," dated June 6, 2018

The purpose of this letter is to provide the NuScale Power, LLC (NuScale) supplemental response to the referenced NRC Request for Additional Information (RAI).

The Enclosure to this letter contains NuScale's supplemental response to the following RAI Question from NRC eRAI No. 8932:

- 03.07.02-4

This letter and the enclosed response make no new regulatory commitments and no revisions to any existing regulatory commitments.

If you have any questions on this response, please contact Marty Bryan at 541-452-7172 or at mbryan@nuscalepower.com.

Sincerely,

Zackary W. Rad
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Enclosure 1: NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 8932

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NuScale Supplemental Response to NRC Request for Additional Information eRAI No. 8932

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Response to Request for Additional Information
Docket No. 52-048

eRAI No.: 8932
Date of RAI Issue: 07/30/2017

NRC Question No.: 03.07.02-4

10 CFR 50 Appendix S requires that the safety functions of structures, systems, and components (SSCs) must be assured during and after the vibratory ground motion associated with the Safe Shutdown Earthquake (SSE) through design, testing, or qualification methods.

On Page 3.7-22 of the FSAR, in the second paragraph, to discuss the adequacy of 7P Extended Subtraction Method (ESM) model, the applicant provided 7P versus 9P ISRS comparisons for the Capitola time histories in Figures 3.7.2-8 to10. However, the FSAR does not provide a comparison of transfer functions for the 7P and 9P models. The review of transfer functions is essential to ensure that the numerical implementation of the SSI analysis methods is acceptable and consistent with the guidance in DSRS Section 3.7.2. In the same paragraph, the applicant also states, “This level of agreement justifies using a 7P versus a 9P model and, because the results are similar, demonstrates the acceptability of using the extended subtraction method as an alternative to the direct method.” The staff believes that 7P vs 9P ESM comparison captures only an “incremental” enhancement between the two models. The adequacy of an ESM model should be established against the direct method (DM). Therefore, in addition to a comparison of the 7P and 9P ESM models, the applicant is requested to provide a comparison of the transfer functions for the 7P ESM and the DM models at selected nodes of the critical sections and other important locations in the RXB and CRB, or, provide technical justification for why a 7P vs 9P comparison is sufficient and acceptable. Guidance in DSRS Section 3.7.2 allows the use of reduced-size models in comparing the solutions of the subtraction or modified subtraction method (SM/MSM) with those of the DM to gain insight into the adequacy of SM/MSM.

NuScale Response:

During a Public Meeting on July 10, 2018, the NRC requested NuScale submit a supplemental response to this RAI. Further, the NRC provided the following details concerning past submittals for this question and clarification needed in the new supplemental response:

In its 04/30/2018 and 06/06/2018 responses to RAI 8932, Question 03.07.02-4, the applicant provided a comparison of seismic responses between the direct method (DM) and extended subtraction method (ESM) for the reactor building (RXB) and control building (CRB), including the transfer functions, ISRS, soil pressures, forces and moments, and relative displacements at key locations.

1) For ISRS, the applicant indicates that a maximum 15% difference is observed between the 7P ESM and DM models for both the RXB and CRB. The staff's concern is that when the 7P ESM underpredicts responses by 15% compared to the DM, such difference may not be negligible in establishing equipment seismic demands. Therefore, the applicant should justify how the observed differences in ISRS between the 7P ESM and DM are acceptable and would ensure conservative equipment seismic demands based on the 7P ESM model.

Response: The ISRS difference of 10 to 15% was observed at narrow frequency bands (i.e., typically within a band of 5 Hz) around ISRS peak locations. This is not a major concern for equipment qualification. The RXB design has enough margin to cover increases in local equipment response due to DM analysis. It should be noted that all major heavy equipment is explicitly modeled in the building models. For example, the Reactor Building Crane, NuScale Power Modules (NPMs), and refueling equipment structures are explicitly modeled in the SAP2000 and SASSI building models. Therefore, the dynamic responses of major equipment are properly incorporated and considered in the analyses.

2) The staff notes that the 7P ESM model underpredicts ISRS by 9.9% compared to DM at the NPM's North Lug Support (Figures 53 and 56 in 04/30/2018 response; Table 8 in 06/06/2018 response). Staff believes that ISRS at the NPM supports are particularly important because they may represent the input for NPM seismic analysis discussed in NuScale TR-0916-51502 (NPM Seismic Analysis). Please address any potential impact of the underestimated ISRS by the 7P ESM on the NPM design and the resulting equipment seismic demands for the SSCs within the NPM.

Response: The ANSYS models result in even higher loads on the lug support, and while those were designed based on time histories from the 7P ESM, there is still capacity available. For example, the maximum ANSYS reaction is 3680 kips. Even 1.1 times that value (i.e., a 10% multiplier which is the difference between the two methods), 4048 kips, is still less than the capacity of 4500 kips. In addition, uncertainties in the NPM analysis and design are accounted for by multiple analysis using +/-30% variation of stiffness, equivalent to approximately a +/-15% variation of the frequencies.

3) The applicant proposed a markup that will augment FSAR Section 3.7.2.1.1.3 by including a new subsection entitled "7P vs Direct Method Comparison". It is noted that, in FSAR Section 3.7.2.1.1.3, an existing subsection entitled "Benchmarking" discusses benchmarking of the 7P model against the 9P model. The staff views that a benchmarking of the 7P model against the DM is more essential than against the 9P model. Therefore, the applicant should consider rearranging and streamlining these affected subsections as appropriate. Comparison between 7P and 9P models may have values and be included in the FSAR; however, 7P vs DM comparison should be emphasized.

Response: FSAR Section 3.7.2.1.1.3 will be rearranged per this comment to emphasize the comparison between 7P and DM for the half model. However, a 7P and 9P comparison using the full model results shows that the 7P full model results are acceptable.

4) In the last paragraph of the proposed FSAR markup (Page 3.7-113, Draft Revision 2), the applicant states that “These comparisons show that the 7P and DM differs, at most, 20% from each other.” Please identify the response quantities that represent 20% difference and justify the acceptance of this level of difference (and expand the FSAR markup to include this justification as appropriate).

Response: The 20% difference in response is between the soil pressure in the north RXB wall at the EL 307.5" soil layer. However, the larger response comes from the 7P model, and is, thus, bounding. This will be noted in the FSAR.

5) In the NuScale Closure Plan, the applicant indicated that 4% structural damping would be used for ESM-DM benchmarking studies for the RXB and CRB. However, in its RAI response, the applicant indicates that 7% damping was used for CRB ISRS generation for a reason given in the RAI response. Please clarify if 7% damping was also used for RXB ISRS generation for the ESM-DM benchmarking study. Also confirm that 7% damping was used in computing forces and moments for the RXB and CRB.

Response: For the ESM-DM benchmarking studies, 4% damping was used for the RXB half models and 7% was used for the CRB full models. For the calculation of forces and moments used in the designs of the RXB and CRB, 7% damping was used for the full models of the RXB and CRB.

6) The staff notes certain differences in the applicant’s responses to RAI 8932, Questions 03.07.02-4 and 03.07.02-6 with respect to the seismic demands shown for the Pilaster finite elements (for the cases of 7P ESM and no soil separation). Explain the reason for the differences or update either or both RAI responses as necessary.

Response: The forces and moments of the two pilasters discussed in RAI 8932, Questions 03.07.02-4 and 03.07.02-6 come from two different analysis models.

The forces and moments in the two pilasters taken from the two models are shown in Tables 1-1 and 1-2 for Pilasters A1 (RXB NW Corner) and A4 (RXB North wall at grid line 4), respectively. As shown in these two tables, the differences are mainly due to different damping ratios used in the two analyses. Also, a half model was used in the ESM-DM study and a full model was used in the soil separation study. This also contributes to the discrepancies. The forces and moments calculated using lower structural damping on two similar models will produce higher responses.

Table 1-1. Forces and Moments in RXB Pilaster A1.

Model (Cracked RXB)		RAI-Half Model	FSAR Full Model
Damping		4%	7%
SASSI Analysis Method		7P ESM	7P ESM
P1 (Kips)	Axial	3,722	2,990
P2 (Kips)	EW-Shear	234	191
P3 (Kips)	NS-Shear	660	451
M1 (Kip-ft)	Torsion	425	382
M2 (Kip-ft)	Moment about EW Axis	10,898	7,991
M3 (kip-ft)	Moment about NS Axis	3,394	2,931

Table 1-2. Forces Moments in RXB Pilaster A4.

Model (Cracked RXB)		RAI-Half Model	FSAR Full Model
Damping		4%	7%
SASSI Analysis Method		7P ESM	7P ESM
P1 (Kips)	Axial	1,141	857
P2 (Kips)	EW-Shear	295	270
P3 (Kips)	NS-Shear	1,811	1,388
M1 (Kip-ft)	Torsion	389	300
M2 (Kip-ft)	Moment about EW Axis	53,261	41,144
M3 (kip-ft)	Moment about NS Axis	2,990	2,788

Impact on DCA:

FSAR Section 3.7.2 has been revised as described in the response above and as shown in the markup provided in this response.

distribute applied loads. The loads are applied as surface pressure on these areas and then transferred to the structural elements through the shared nodes. These coarse elements are not present in the seismic analyses and will not, therefore, affect the seismic demand results. In the RXB model, there are 24 elements with approximate dimensions of 12 ft x 6 ft at the pool floor. These are transition solid elements beginning in the top layer of solid elements used to model the basemat. The mesh transitions into the uniform soil mesh, matching the soil interaction nodes at the base elevation of the basemat, with an average element size of approximately 6.25 ft. The single layer of coarse basemat transition elements have minimal or no effect on the seismic analysis results.

Modeling Approach

Analysis Methods

There are several modeling approaches that can be used for modeling the excavated soil in the SSI analysis: the direct method (DM), the subtraction method (SM), the modified subtraction method (MSM), and the extended subtraction method (ESM). Each method has different computational demands. A brief discussion of the different methods follows:

RAI 03.07.02-4S2

The direct method partitions the soil structure system between the building and the excavated soils. It requires only the free-field motions and the free-field soil impedances to compute the seismic excitations on the foundation of structure. The soils to be excavated are retained with the foundation. Therefore, interaction between the structure and the foundation is calculated at all excavated soil nodes. In the analysis, the DM treats all translational degrees of freedoms of the excavated soil as SSI interaction nodes. This corresponds to a theoretically exact SSI model for the excavated soil dynamics. DM analysis is computationally intensive and cannot be used with the large detailed models created for the NuScale buildings.

RAI 03.07.02-4S2

To reduce computational time, a simplified method, called the subtraction method, was developed. The SM assumes only the nodes at the interface of the excavated soil volume and surrounding free field soils act as interaction nodes. In mathematical implementation, only those specified interaction nodes are described by ~~correct~~ equations of motion. The seismic load component and free-field soil impedance are neglected for the non-interaction nodes within the excavated soil volume. Therefore, the excavated soil motion can produce spurious vibration modes. This simplification results in anomalies in the transfer functions, usually seen as spurious spikes for soft free-field soils at relatively high frequency ranges. The SM approach for the excavated soil can be visualized as the five planes that represent the sides and bottom of the "box" that models the excavated volume.

The modified subtraction method includes the nodes at the ground surface of the excavated soil as interaction nodes. The MSM approach for the excavated soil can be visualized as the six planes that represent the sides, bottom, and top of the "box" that models the excavated volume. The inclusion of the ground surface nodes as interaction nodes provides significantly improved boundary conditions and improves the excavated soil response accuracy.

RAI 03.07.02-4S2

Within SASSI2010, a further enhancement of the MSM is available; this methodology is called the extended subtraction method. In the ESM, intermediate planes may be defined within the excavated volume. The addition of intermediate planes reduces the amount of interpolation that must be performed within the excavated volume, and further improves the accuracy of the excavated soil response. As additional planes are added, the ESM approaches the DM in both accuracy and computational time. The NuScale buildings are evaluated with an ESM model.

RAI 03.07.02-4S2

Ensuring Accurate Results

RAI 03.07.02-4S2

Both the MSM and ESM reduce the potential for the spurious results produced by the subtraction method. The use of intermediate planes in the ESM method make it even less likely than the MSM to produce inaccurate results. When they occur, these errors can be seen in the transfer functions. However, due to the size and complexity of these models, it is not practical to review transfer functions at all the nodes in the models. Therefore, errors are found by questioning unexpected results. During those investigations, transfer functions may be plotted and reviewed. However, no anomalies associated with using the subtraction method have been seen.

RAI 03.07.02-4S2

The design process for the site-independent RXB and CRB is to consider multiple soil types, two building stiffnesses (for cracked and uncracked concrete), and multiple time histories. This large data set makes it more likely to notice an anomaly, since it is unlikely to occur in all the different combinations used as input.

RAI 03.07.02-4S2

For the CSDRS, the results from five time histories were averaged for each soil type to produce a single set of results for that soil type. These results are then combined and the maximums are used (i.e., the results are enveloped). For the determination of forces, moments, and shears, the results from the CSDRS-HF analysis are also included and, thus, bounded by the design. Averaging reduces the potential for a spurious peak to drive an overly conservative design. Bounding the two stiffnesses and various soil combinations ensures that a spurious low point will not result in an inadequate design.

RAI 03.07.02-4S2

Two other aspects of the design process also ensure the acceptability of the structures.

- Standardized design of walls. The thicknesses and internal steel reinforcement of the primary walls are generally consistent throughout each building. Areas where forces are lower are not optimized for the local load.
- Site-independent design. A site-specific analysis is performed to confirm that the design is adequate for that specific location. A different SSE and soil column will not produce anomalies at the same locations. A spurious low point will not result in a change to the standardized design.

Benchmarking

RAI 03.07.02-4S2

For the analysis of the Seismic Category I RXB and CRB with the extended subtraction method, a single intermediate plane was used. This approach is designated as 7P, to reflect the four sides of the excavated volume, and the top, bottom, and middle horizontal planes. Benchmarking of the 7P approach was performed by comparing the results to the DM and to a nine plane model.

RAI 03.07.02-4, RAI 03.07.02-4S2

7P vs Direct Method Comparison

RAI 03.07.02-4, RAI 03.07.02-4S2

Comparisons between the DM and 7P ESM have been performed for the CRB and RXB. ISRS and transfer functions have been generated from both methods and compared.

RAI 03.07.02-4, RAI 03.07.02-4S2

The ISRS calculated by the CRB 7P model are very close to those calculated by the DM model. There are some increases found in several ISRS. A direct comparison with the DCA ISRS cannot be provided due to differences in the structural damping values used in the CRB ISRS generation model (4% structural damping) and the CRB design model (7% structural damping).

RAI 03.07.02-4, RAI 03.07.02-4S2

However, the ISRS generated at 7% structural damping for 7P and DM produced results that are within 15% of each other. Most corresponding values from each model are the same.

RAI 03.07.02-4, RAI 03.07.02-4S2

The transfer function shapes calculated by the CRB 7P model are nearly identical to those calculated by DM, with the exception of a few peak values. No spurious peaks are found in the transfer functions.

RAI 03.07.02-4S1, RAI 03.07.02-4S2

Additionally, forces, moments, and displacements in the CRB exterior walls from both methods are compared. These results are within 10% of each other. See Table 3.7.2-46 and Table 3.7.2-44.

RAI 03.07.02-4, RAI 03.07.02-4S2

To use the direct method for the SASSI SSI analysis of the full RXB model, the number of required interaction nodes (28,830) exceeds the SASSI2010 program limit of 20,000. Therefore, a half model was used to obtain the results by the DM.

RAI 03.07.02-4, RAI 03.07.02-4S1, RAI 03.07.02-4S2

The ISRS calculated by the RXB 7P model are also within 15% of those calculated by the DM model. Similar to the CRB, the transfer function shapes show excellent agreement between 7P and DM, except at a few peak values. At some limited locations in the model, large differences are observed at specific frequencies which do not affect the results.

RAI 03.07.02-4, RAI 03.07.02-4S2

No spurious peaks are introduced in most of the RXB transfer functions. Spurious spikes are seen in some transfer functions for both 7P and DM, but do not affect the RXB ISRS. Oftentimes, adding a frequency point or shifting the frequency close to a spike location eliminates the spurious spike.

RAI 03.07.02-4S1, RAI 03.07.02-4S2

Soil pressures, forces, moments, and displacements at key locations in the RXB are also compared between the two methods. These comparisons show that the 7P and DM differ, at most, 20% from each other. The 20% difference in response is between the soil pressure in the north RXB wall at the EL 307.5" soil layer. However, the larger response comes from the 7P model, and is, thus, bounding. See Table 3.7.2-48, Table 3.7.2-45, and Table 3.7.2-47.

RAI 03.07.02-4S2

7P vs 9P Comparison

In the 9P model, additional planes are added above and below the center plane, halving the vertical distance used for interpolation of results. This benchmarking was performed to confirm that the results of the 7P and 9P model were similar and further confirms that the ESM approaches the DM in accuracy.

The comparison of 7P to 9P is accomplished by looking at the in-structure response spectra (ISRS) at three locations in the reactor building:

- The northeast corner on top of the basemat as shown in Figure 3.7.2-5.
- The NPM1 East bay wall at the lug support as shown in Figure 3.7.2-6.
- The center of the roof slab as shown in Figure 3.7.2-7.

RAI 03.07.02-4S2

In addition, bending moments at the center of the roof are compared to investigate if the moment responses calculated by the analysis using the 7P interaction nodes are close to those from the analysis using the 9P interaction nodes. These comparisons are performed with the CSDRS and all five CSDRS-compatible time histories for Soil Type 11 (soft soil) and Soil Type 7 (rock) using cracked concrete and 4 percent damping.

The 7P versus 9P ISRS comparisons for the Capitola time histories are provided in Figure 3.7.2-8, Figure 3.7.2-9, and Figure 3.7.2-10. The corresponding results for the other time histories are similar. As can be seen in these figures, there is very close correlation between the 7P and 9P models, with the larger variation occurring in the soft soil. This level of agreement justifies using a 7P versus a 9P model and, because the results are similar, demonstrates the acceptability of using the extended subtraction method as an alternative to the direct method.

While the results are similar, they are not exact. This difference is not a concern because of the methodology used in developing accelerations and forces in the structures. Each building is evaluated with several soil types and two stiffnesses. In addition, for the CSDRS, five separate time histories are evaluated, and the results are averaged.

RAI 03.07.02-4S2

~~Ensuring Accurate Results~~

~~Both the MSM and ESM reduce the potential for the spurious results produced by the subtraction method. The use of intermediate planes in ESM method make it even less likely than the MSM to produce inaccurate results. When they occur, these errors can be seen in the transfer functions. However due to the size and complexity of these models it is not practical to review transfer functions at all the nodes in the models. Therefore errors are found by questioning unexpected results. During those investigations, transfer functions may be plotted and reviewed. However, no indication of the anomalies associated with using the subtraction method have been seen.~~

~~The design process for the site independent RXB and CRB is to consider multiple soil types, two building stiffnesses (for cracked and uncracked concrete), and multiple time histories. This large data set makes it more likely to notice an anomaly since it is unlikely to occur in all the different combinations used as input.~~

~~For the CSDRS, the results from five time histories were averaged for each soil type to produce a single set of results for that soil type. These results are then combined and the maximums are used (i.e., the results are enveloped.). For the determination of forces, moments and shears, the results from the CSDRS-HF analysis are also included and thus bounded by the design. Averaging reduces the potential for a spurious peak to drive an overly conservative design. Bounding the two stiffness and various soil combinations ensures that a spurious low will not result in an inadequate design.~~

~~Two other aspects of the design process also ensure the acceptability of the structures.~~

- ~~Standardized design of walls. The thicknesses and internal steel reinforcement of the primary wall are generally consistent throughout each building. Areas where forces are lower are not optimized for the local load.~~
- ~~Site-independent design. A site specific analysis is performed to confirm that the design is adequate for that specific location. A different SSE and soil column will not produce anomalies at the same locations. A spurious low would not result in a change to the standardized design.~~

Cracked Model Stiffness

For SASSI2010 analyses, the plate stiffnesses are only controlled by two input parameters. The two parameters are the Young's modulus and the plate thickness. It is not possible to reduce the bending stiffness by 50 percent for cracked concrete while preserving the axial stiffness at 100 percent for in-plane forces by modifying Young's modulus. A compromise approach is used by reducing the thickness by a factor equal to cubic root of 0.5, or 0.7937 to reduce the bending stiffness in half for the cracked concrete condition. In this approach, the uncracked axial stiffness is reduced by a factor of 0.7937.

Soil Separation

A study was performed to investigate the effects of a gap forming between the RXB and the backfill soil during an earthquake.

The RXB was analyzed for Soil Type 7 with cracked concrete properties and 7 percent concrete material damping. Soil Type 7 was chosen because that is the case that produced the highest ISRS and forces and moments at the majority of the locations. Cracked concrete properties were chosen to be consistent with the use of 7 percent damping for the concrete material.

To model the soil separation, the Young's modulus of the backfill elements down to a depth of 25′ (the top four layers of backfill elements) was decreased by a factor of 100.

RAI 03.07.02-6

Soil separation has negligible effect on the response of the structure. ~~The primary point of comparison is at the NPM. The study showed that the maximum reaction force at the base of the NPMs decreased by approximately 5 percent, and the maximum reaction force at the NPM lug restraints decreased by more than 15 percent. In addition to examining the forces on the NPM, the in-structure response spectra were compared at the top of the basemat and the roof of the building. The ISRS virtually overlay each other, comparable in shape, and peak of response. Therefore, based upon the results of this study, modeling the structures as fully embedded is an acceptable design~~