Official Transcript of Proceedings

NUCLEAR REGULATORY COMMISSION

Title:	Advisory Committee on Reactor Safeguards NuScale Subcommittee Open Session
Docket Number:	(n/a)
Location:	teleconference
Date:	Tuesday, September 22, 2020

Work Order No.: NRC-1105 Pages 1-86

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

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UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

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ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

(ACRS)

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NUSCALE SUBCOMMITTEE

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TUESDAY

SEPTEMBER 22, 2020

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The Subcommittee met via Video Teleconference, at 2:00 p.m. EDT, Peter Riccardella, Chairman, presiding.

COMMITTEE MEMBERS:

PETER RICCARDELLA, Chairman

MATTHEW W. SUNSERI, Member

JOY L. REMPE, Member

WALTER L. KIRCHNER, Member-at-large

RONALD G. BALLINGER, Member

CHARLES H. BROWN, JR. Member

VESNA B. DIMITRIJEVIC, Member

JOSE MARCH-LEUBA, Member

DAVID A. PETTI, Member

DESIGNATED FEDERAL OFFICIAL:

DEREK WIDMAYER

CHRISTOPHER BROWN

ALSO PRESENT:

JOSEPH COLACCINO, NRR

MARTY BRYAN, NuScale

SUNWOO PARK, NRR

JOSH PARKER, NuScale

KYRA PERKINS, NuScale

MATTHEW SNYDER, NuScale

MICHAEL DUDEK, EDO

WILLIAM WARD, NRR

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P R O C E E D I N G S

2:00 p.m.

CHAIR RICCARDELLA: Good afternoon. The meeting will now come to order.

This is a meeting of the Advisory Committee on Reactor Safeguards, Subcommittee on NuScale.

I am Pete Riccardella, a member of the Subcommittee, and I am going to be chairing this meeting.

ACRS members in attendance are, that I can see so far, Joy Rempe, Ron Ballinger, Walt Kirchner, Dave Petti, Vesna Dimitrijevic, Jose March-Leuba, and Matt Sunseri. We're expecting Charlie Brown to join us.

Charlie, have you joined yet?

(No response.)

Okay. I believe Charlie will be able to join us.

Derek Widmayer of the ACRS staff is the Designated Federal Official for this meeting. Christopher Brown of the ACRS staff will be the backup Designated Federal Official.

The purpose of today's meeting is to discuss NuScale Topical Report, "Improvements in

Frequency Domain Soil-Structure - Fluid Interaction Analysis," and the staff's Safety Evaluation.

The Subcommittee will get information, analyze relevant issues and facts, and formulate proposed positions and actions as appropriate. This matter is scheduled to be presented to the full Committee at the October 2020 full Committee meeting.

ACRS was established by statute and is governed by the Federal Advisory Committee Act, FACA. The NRC implements FACA in accordance with its regulations found in Title 10 of the Code of Federal Regulations, Part 7.

The Committee can only speak through its published Letter Reports. We hold meetings to gather information and perform preparatory work that will support our deliberations at our full Committee meeting.

The rules for participation in all ACRS meetings, including today's, were announced in The Federal Register on June 13th, 2019. The ACRS section of the U.S. NRC public website provides our Charter, Bylaws, agendas, Letter Reports, and full transcripts of all full ACRS meetings, including slides presented there. The meeting notice and agenda for the meeting were posted there.

As stated in The Federal Register notice and in the public meeting notice posted to the website, members of the public who desire to provide written or oral input to the Subcommittee may do so and should contact the Designated Federal Official five days prior to the meeting, as practicable.

Today's meeting is open to public attendance, and we have received no written statements or requests to make oral statements. We have also set aside 10 minutes in the agenda for spontaneous comments from members of the public attending or listening to our meetings. If necessary, we will convene a closed session of our Subcommittee on a separate Skype connection to discuss material that is deemed proprietary by NuScale.

Due to the COVID pandemic, today's meeting is being held over Skype for ACRS and NRC staff attendees. There is also a telephone bridge line allowing participation of the public over the phone.

A transcript of today's meeting is being kept. Therefore, we request that meeting participants on the bridge line identify themselves when they are asked to speak and to speak with sufficient clarity and volume, so that they can be readily heard.

At this time, I ask that attendees on

Skype and on the bridge line keep their devices on mute to minimize distractions and unmute only when speaking.

We will now proceed with the meeting, and I call on Michael Dudek of the NRC staff to introduce this topic. NuScale will, then, proceed with its presentation.

Michael, are you there?

MR. DUDEK: I am. Thank you. Thank you, Chairperson Riccardella.

And thanks to the esteemed members of the Subcommittee that are going to be hearing this topic today.

And I'd like to especially thank Derek Widmayer and Sunwoo Park who did an outstanding job collaborating and coordinating this meeting, as well as my Project Manager who brought this home and helped facilitate setting up everything associated with this meeting.

Today, you're going to hear about a proposal from NuScale in the form of a Topical Report that proposes an analytical tool to help fill the gap of integrating the effects of soil-structure and fluid interaction in the development of seismic loads for licensing of the nuclear power plants, especially small modular reactors.

Previously, there has been no analytical tool available for this systematic integration of these items. However, this Topical Report is a new, novel approach being proposed by NuScale that is going to bring these methodologies and interactions together and the capabilities with two analytical tools that will, hopefully, allow both NuScale and the staff to move forward on these interactions and this topic in a very collaborative and analytical way.

Sunwoo Park has done an excellent job, as you've seen in the SER that's been delivered to you, in a transformational approach to try to analyze and assess how these things work together. And as you'll see in the SER, has approved his version of the proposal that is currently going through management for final review on "how to" and approving NuScale's Topical Report.

So, without any further ado, I'll turn it over to NuScale for any opening remarks, or back to you, Mr. Chairperson Riccardella.

CHAIR RICCARDELLA: Yes. This is Pete Riccardella.

I just wanted to acknowledge that I see from the participant list that Charlie Brown has joined the meeting. So, we have, basically, all ACRS members with the exception of Dennis Bley, who said he couldn't attend.

MEMBER BROWN: Thanks, Pete.

CHAIR RICCARDELLA: So, NuScale, go ahead.

MR. SNYDER: All right. This is Matthew Snyder.

If you'll move to slide 4, please.

All right. Thank you.

The soil-structure interaction analysis methodology described in this report has been called the soil library method or soil library seismic method. And I'll use that term throughout the talk here.

And the reason for that is one of the unique features is that it combines soil impedance and load factors that are provided in written input as soil library file, and that file is calculated by the soil-structure interaction program SASSI. For comparison to the soil library method, in the following I'll also refer to methodology used in the DCA as the current methodology or DCA methodology.

The soil-structure interaction analysis methodology used for design certification was also a frequency domain analysis with fluid-structure interaction and was performed using SASSI. The main point I want to make is that the improved or replacement methodology still uses the program SASSI and it's functionally equivalent to the current design certification methodology. The purpose of the improvements is to allow a more efficient process. It permits much more detailed modeling with fewer simplifications in the analysis.

Next slide, please.

Some of the advantages of the new soil library method are listed here. The current DCA analysis uses at least seven different separate structural models or submodels and a multi-step approach. In the new approach, this is replaced with one model in one step. With the new method, the same finite element program in mesh can be used for non-seismic loads, making load combinations easier to perform. In the DCA, there were separate finite element models for non-seismic loads. The one model and one step eliminates that complicated process of developing those multiple models and mapping output from the mesh of one as input to the mesh of the next model.

The new soil library method also allows much larger and detailed structural models. This will permit us to include detailed models of all 12 of our modules easily in one model without simplifications.

The new model uses ANSYS, which has much more extensive capabilities and advanced features when compared to the structural elements in SASSI. And ANSYS has very efficient solvers capable of much larger problems than the current SASSI code.

Next slide, please.

Given its efficiency and capability for more detailed modeling, the soil library method should be the preferred method for future analysis. NuScale is intending to use the soil methodology for detailed design certification and the SDA. It would also be expected that most site-specific analysis would be performed using soil library methods. In that case, the COL applicant would need to generate their own soil library for site-specific with soil properties bounding the site-specific profiles.

Next slide, please.

This does not take away from the current design certification methodology. The current methodology used in the design certification is accurate in conserving the valuation of loads and demands and fully conforms to NRC regulatory guidelines.

However, the current methodology uses a multi-step dynamic analysis of the building and major substructures such as the paramodules. An initial step in the frequency domain is followed by detailed modeling in the time domain. This leads to excessively large turnaround times for reanalysis of design changes and studies. On the next slide, I'll show the complexity of the DCA methodology.

MEMBER MARCH-LEUBA: Sorry to interrupt.

MR. SNYDER: Yes?

MEMBER MARCH-LEUBA: This is Jose.

Can you go back to slide 6, where we started this? What is the purpose of this Topical Report? Because the site specifications have already been approved on this; the ink has already been approved, right? Are you trying to approve it again, or what?

MR. SNYDER: No, we are not saying that. We're asking to use this methodology because of its efficiency and ability to model in much greater detail.

MEMBER MARCH-LEUBA: Yes, I get that, but use the methodology for -- do we have an echo?

MR. SNYDER: The methodology essentially replaces that methodology described in Section 372 for seismic soil-structure interaction at the reactor building.

MEMBER MARCH-LEUBA: Right, but --

CHAIR RICCARDELLA: This is Pete, Jose.

So, could we characterize this, then, as requesting approval of a Topical Report in anticipation of a COL applicant using it? Correct? It's past the DCA.

MR. SNYDER: Maybe the other people should answer that, but my answer would be that a COL applicant could use the original DCA, of course, or his own analysis.

CHAIR RICCARDELLA: Could somebody from NuScale licensing please answer that?

MS. PERKINS: Yes. This is Kyra Perkins.

So, the intent of this would apply now to these standard design approval application, not the DCA. And the intent is to use it for site-specific co-applicants, as indicated.

CHAIR RICCARDELLA: Jose, does that answer your question?

MEMBER MARCH-LEUBA: Yes, I mean, it was obvious that it is for the site-specific application, but --

CHAIR RICCARDELLA: Yes.

MEMBER MARCH-LEUBA: -- I keep getting confused. I wanted to make sure I was not missing anything.

Thank you.

MEMBER REMPE: This isn't my area, but when I was reading this, this sure seems like it must have been really hard to use the other method when you've got 12 modules and a swimming pool and one building because of the interactions between the modules and the water, and everything. I mean, they make some comments about this in this presentation and in the report, about it makes a method a lot easier because you don't have to do a lot of transferring between analyses. And I think the boundary conditions, having one method would just be so much more logical.

MR. SNYDER: I'm sorry, my speaker dropped off. I didn't catch if there's a question for me.

MEMBER REMPE: Well, I mean, wouldn't it have been really hard to have used the other methods when there's boundary conditions between modules? I mean, I just thought that must be why you guys decided to spend the money to do this method, because it was just so difficult to try and do it with the existing tools that were designed for a single unit and a reactor building that interfaced with the ground.

MR. SNYDER: Yes, the existing method --

MEMBER REMPE: Now you're dropping off. I can't hear your response. You're doing to have to do it again.

MR. BRYAN: Yes, Joy, this is Marty Bryan. Can you hear me okay?

MEMBER REMPE: Yes.

MR. BRYAN: How are you doing?

Yes, so you're right, and I think we'll talk about it in a couple of slides. But this is a much more, I would use the term, efficient method. So, the other one gave us valid conservative results, but I think in a couple of slides we talk about the processing time with this is on the order of a magnitude quicker by doing it this way. So, I think we would agree with your assessment that this is a faster way of getting results. So, we'll go into that in a little more detail in the slides coming up.

MR. SNYDER: I'm sorry, I --

MEMBER REMPE: We'll wait until the next slides come up, but I almost think it would have been really hard to have done something with real -- there's interfacing boundary conditions between the modules.

MR. BRYAN: Yes.

MR. SNYDER: I'm sorry, I dropped off for a while. So, I hope I'm not interrupting.

MR. BRYAN: Go ahead, Matthew.

CHAIR RICCARDELLA: No, go ahead.

MR. BRYAN: Okay. I think I was talking to the air here. But I think you answered the question.

Which slide? We're on this background slide.

CHAIR RICCARDELLA: You were on slide 7, I believe.

MR. SNYDER: We just finished slide 7, and that's when a question came up, I think.

CHAIR RICCARDELLA: Yes.

MR. SNYDER: But let's go on to slide 8 because it starts to show the complexity of the DCA process. And here, we're talking a difference of sometimes months, if a change was made in this sequence of model, versus days, or at the most weeks. So, it's a significant factor when you consider the number of times that these models are run during the process of finalization of a design and during a COL applicant or the other future uses.

On slide 8, this slides shows the multiple finite element and submodels and steps in the current methodology. If you look on the lower righthand corner, the model of the reactor building is done in SASSI. That SASSI model is generated by translating a SAP2000 model into SASSI. And so, there's a separate SAP2000 model maintained for non-seismic loads.

In the SASSI model, there's a simplified model of the reactor modules. It's not very detailed. It's a lumped mass beam model with lumped mass springs representing fluid-structure interaction between the module and the building.

But this SASSI model is the source of the design forces and in-structure response spectra in the building. The other models, the following sequence of models is used to determine design forces and in-structure reaction, in-structure response spectra on the module itself.

So, the sequence following, as you move from the lower right to the lower left, it changes from analysis in the frequency domain to analysis in the time domain. And there's a detailed model of the pool with the reactor module in it. And then, that's followed by still another step to analyze the reactor module bay.

Now the original dynamic model of the reactor, the SASSI model, includes a simplified model of the reactor module. So, there's a requirement to develop a dynamically equivalent beam model that's small enough to still be incorporated into SASSI.

And then, there's also this additional process of just mapping analysis results between the individual finite element models, because they have different meshes. We call those cut-boundaries. There's sometimes interaction boundaries. So, those forces and displacements on that boundary are originally unknowns, and when you change meshes, you have to be sure you have enough detail in the original model that you represent that interaction correctly.

CHAIR RICCARDELLA: This is Pete Riccardella.

MR. SNYDER: Yes?

CHAIR RICCARDELLA: In the lower righthand corner of the slide, you have the building model that goes into SASSI. How is the water, the weight of the water, incorporated? Just as mass in that model?

MR. SNYDER: The main pool is lumped mass.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: But surrounding each module we added a mass-spring model that represents fluid interaction forces acting between the walls and the module.

CHAIR RICCARDELLA: Yes, but those don't get fed back into the SASSI model, do they? I'm asking, do those get fed back into the SASSI --

MR. SNYDER: Those --

CHAIR RICCARDELLA: I'm sorry, go ahead.

MR. SNYDER: Yes, that simplified fluid-structure interaction between the modules and the walls is in the SASSI model.

CHAIR RICCARDELLA: Okay, okay.

MR. SNYDER: Yes, it's translated into the SASSI model.

CHAIR RICCARDELLA: As spring-mass --

MR. SNYDER: As spring-mass, yes.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: Whereas, for the final analysis of the module, we've taken results from SASSI and pose those on the pool, and then, on the detailed model of the --

CHAIR RICCARDELLA: Okay.

MR. SNYDER: So, that's the sequence. Is it clear?

CHAIR RICCARDELLA: I think so, yes.

MR. SNYDER: The reason for this sequence in the past was primarily to overcome the limitations of structural elements and problem size available to SASSI.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: It's typical of analysis to do two steps, and sometimes it's necessary because of design areas of responsibility. But here, we can integrate into one single approach. The soil library method overcomes these limitations by reducing all these seven models to a single, actually, much more detailed ANSYS structural model. And essentially, we don't have severe limitations on problem size.

Next slide, please.

Any other question on this?

(No response.)

Let's go to 9 then.

In the soil library method, the seismic analysis is reduced to a single model, including the pool and power modules. The analysis is performed in the frequency domain without need for a second step in the time domain. By using soil impedance and load vectors from SASSI, the current analysis approach is replaced by a functionally equivalent, but simpler approach.

But the analysis is shortened by an order of magnitude. And I may have said this before, but it might have been when I was cut off there, so I'm going to repeat it. The analysis is shortened by up to an order of magnitude in terms of calendar time. Typically, a sequence of analysis for a change in these models involves a month of calendar time to redo it, and that's been reduced by an order of magnitude by this process.

SASSI also has a very limited library of structural elements, besides its restrictive problem size. And for that reason, most analyses using SASSI have relied in the past on the second step, where needed. The acoustic elements are not in SASSI, except in the current DCA process we are including acoustic elements to represent the pool in that second step. So, the DCA methodology does represent the acoustic element, but, as we said before, it's the simplified model in the SASSI model itself.

Next slide, please.

MS. PERKINS: Are there any questions on this slide?

MR. SNYDER: Pardon me. Yes, you should be on slide 10. I've got a different slide somehow.

MR. BRYAN: Yes, Matthew, go ahead. This is Marty. Go ahead. We were just pausing there to see if there were any questions.

MR. SNYDER: Yes. The problem is it's -- oh, okay, it's on the right one. I thought I had a wrong set of slides because I have a very small picture coming from you. So, I have to put it up separately. We are on slide 10.

In the soil library method, SASSI is used to obtain the soil impedance and load vectors in the frequency domain. These are the dynamic stiffness of the soil profile itself, of the excavated soil. There's no change in actual seismic inputs in soil properties that we will use in this analysis methodology. We're going to fully conform to the guidelines for using SASSI.

The soil library method functionally uses the same SASSI representation of the soil, but it's using, instead of the SASSI structural representation, it's using an ANSYS structural model. The replacement of the soil, the structural model -- I'm sorry, I lost my track.

Structural modeling and the solution of the dynamic equations are performed entirely in the frequency domain using the ANSYS model. They can be changed without requiring regeneration of a soil library. Post-processing and transformation of the response to the time domain is performed efficiently in ANSYS using the same methods as in SASSI. There's no customization or special programming required for ANSYS at all.

For the soil library method, there's three methods of doing an embedded structure in SASSI: a direct, a modified subtraction, and a subtraction. I'll explain these a little more on the next slide. But the soil library method, because of its ability to solve much larger problems, we're able to use the direct method, which is always acceptable.

Next slide, please.

MS. PERKINS: Matthew, let's pause here -- after each slide.

Does the ACRS have any questions?

CHAIR RICCARDELLA: This is Pete. I have some questions building up, but I want to wait before I get into them.

MS. PERKINS: Okay. We'll move on.

MR. SNYDER: All right. Slide 11.

In summary, the soil library method is performed in the frequency domain. It consists of three parts: the soil impedance from SASSI, the ANSYS structural model, and using the ANSYS equation solver in post-processing.

(Pause.)

CHAIR RICCARDELLA: So, have we lost Matthew?

MEMBER REMPE: I don't hear anything. I was wondering if it was just my connection going bad.

MR. BRYAN: Yes. This is Marty Bryan. I think we did.

MR. SNYDER: Hey, I'm back now.

CHAIR RICCARDELLA: Yes, you're back.

MR. SNYDER: I don't know where I left off, Pete. Can you tell me?

MEMBER KIRCHNER: Matthew, this is Walt Kirchner.

I think you were on that sub-bullet, that you use SASSI. I think that the point that you're trying to make here is you can fully avail yourself of a much more detailed ANSYS structural model rather than the limitations of the SASSI code. At least, that's the way I understand it.

MR. SNYDER: Okay. Yes. And then, I also wanted to -- we're on slide 11 -- I also want to point out that we validated this using example problems that ranged from a simple structure to the NuScale SMR. All the problems we verified, and the way we verified was by importing the ANSYS structural matrices into

SASSI and solving using the SASSI solver. So, that sequence of soil impedance, SASSI; ANSYS structural model, plus ANSYS solver, would be replaced by SASSI solver in the end.

Now, for simpler problems, where you can make the analysis in SASSI itself, we have compared to classical SASSI, where we use a SASSI -- it's called "a house module" -- where the structural model from SASSI comes. So, we've used a classical SASSI solution for a very simpler problem for comparisons. And we can explain that more when we talk about the example problems.

We're still restricted to the same limitations as SASSI. The methodology assumes equivalent linear elastic analysis. No changes made to the analysis of secondary soil, structures, and the fuel. They're designed using in-structure or response spectra or time histories obtained from this building model.

CHAIR RICCARDELLA: Okay. This is Pete. A couple of questions on that.

MR. SNYDER: Yes.

CHAIR RICCARDELLA: So, there obviously will be some earthquake magnitudes and soil conditions for which the linear elastic assumption breaks down.

Do you have some -- I don't know -- post-analysis checks that you do to check the stresses and soils and other aspects of it to confirm that the linear assumptions are valid?

(No response.)

Hello?

MEMBER KIRCHNER: I think, Pete, we may have lost Matthew again.

MR. SNYDER: I'm back now.

CHAIR RICCARDELLA: Yes, you're back. Did you hear my question or --

MR. SNYDER: No, I dropped right when you started.

CHAIR RICCARDELLA: Okay. So, what I was saying is there are obviously some earthquake magnitudes and soil conditions for which the linear assumption won't apply. And do you do some post-analysis checks after you've finished the analysis to confirm that you're still within the realm of linear behavior and bounding conditions?

MR. SNYDER: Well, that question is a little outside of the -- we would do the same things with this methodology as we would in previous.

MEMBER KIRCHNER: Okay. So, Matthew, this is Walt Kirchner.

Maybe a different way to ask Pete's question: are there soil conditions where you know a priori -- say sand; hopefully, we don't put a plant in sand -- where you know linear elastic wouldn't -- you would be outside that kind of a boundary condition? Or, as Pete infers, a high enough G-loading that the linear elastic bases no longer applies?

MR. SNYDER: Well, I suppose it is possible, but for all the sites we know of we would probably be within the bounds of the applicability of this.

CHAIR RICCARDELLA: Okay. Yes, I just wondered if you have some specific checks that you do after you've completed an analysis to confirm that the linear elastic analysis applies.

DR. PARK: Yes, this is Sunwoo Park, NRC staff member.

CHAIR RICCARDELLA: Yes.

DR. PARK: If I may chime in with a comment to the question?

CHAIR RICCARDELLA: Sure.

DR. PARK: The soil properties is well known. And like you suggested, those soil properties, especially stiffness and damping, the characteristics, they depend on the level of the earthquake. You know, the high magnitude earthquake will disturb soil more and resulting in different stiffness, for example, characteristic.

So, those, they are well-known; that is, the earthquake-dependent soil properties. And there is a way to combat that situation, which is known as an iterative process in which there is a series of iterative analysis that is conducted in the seismic response analysis stage. The seismic response analysis involved is the analogies of soil layers only and not involving super-structure subject to an earthquake. And there is a program that can perform iterative analysis, and then, finally, the analysis provides the final -- the equivalent linear elastic, the properties of the soil.

CHAIR RICCARDELLA: I see.

DR. PARK: That is commensurate with the level of the earthquake that you are considering.

CHAIR RICCARDELLA: I see.

MR. SNYDER: Yes, I think I would add that, yes, we use equivalent linear -- and they are actually very bounding conservative assessments of damping and stiffness for the soil. And the straining levels in the soil are assessed in order to determine the soil properties.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: Now, on the structure itself, we can have non-linear conditions. We have a module that could potentially lift off. And we will be running additional analysis as a second step with non-linear conditions. But even this soil method has the advantage that the source for that input is the detailed model itself. So, you're not applying input time histories from a simplified model onto a detailed model where you've introduced non-linear conditions. Is that clear?

CHAIR RICCARDELLA: I think so.

MEMBER KIRCHNER: Matthew, just probably getting ahead of your presentation, when you get to the actual 12 modules and the large reactor building for the full design analysis, does something like sloshing of the pool, then, put you into a non-linear kind of response mode?

MR. SNYDER: The fluid elements that we're using in these models are acoustic elements. There is limited linear sloshing capability. Normally, we'll run these seismic models separately from a sloshing analysis, just because the sloshing is at such a low frequency, it's not amenable to inclusion in this.

MEMBER KIRCHNER: Well, maybe we can come back to that when you present your final example problem.

Just one other question. And I'll show that I'm not a structural engineer. Do you ever get to a point where the mass, the size and mass of the excavated -- I'm not phrasing this well. The soil excavation, and so on, is there a point where the mass -- I guess it's a function of the soil, and you wouldn't locate in a soil structure that couldn't bear the mass. But are there any effects where you have such a -- you know, you have like a cross-section of a super-tanker, essentially, for that reactor building filled with water and the modules. Are there any points where you get to size and mass, that these kind of linear elastic analyses are affected?

MR. SNYDER: I'm not sure I know how to answer because I'm not understanding exactly what you're asking there. Do you mean -- and it comes back to the same question of, I think, can we use this equivalent linear elastic analysis for soil that has non-linear strain-dependent properties?

MEMBER KIRCHNER: I guess that's it. I was just thinking, are there combinations of both soil and the size and mass of structure that your reactor building is that would -- you know, going in, you just wouldn't use this approach, or you wouldn't use that site, I guess, really is the screening criteria.

MR. SNYDER: Yes, I think that's more the answer. They certainly wouldn't build it on a peat bog or something, you know.

But, no, we intend to use this method for a large range of sand and softer-soil sites, if needed. Actually, the more critical sites we've seen for the reactor module standpoint are the rock sites.

MEMBER KIRCHNER: Yes. That means you're getting more amplification on a rock site for your reactor modules.

MR. SNYDER: Yes, or you're getting less benefit of SSI, if you.

CHAIR RICCARDELLA: Yes. Okay. Thank you.

MR. SNYDER: Okay. I think we're done with this, 11. Any more questions on 11?

(No response.)

Okay. Let's move to 12. All right. It is not coming up on my end, but if you're ready --

CHAIR RICCARDELLA: It's up. It's up on my screen.

MR. SNYDER: Okay. Well, yes, as long as you hear me.

CHAIR RICCARDELLA: Yes.

MR. SNYDER: To represent soil-structure interaction for embedded structures, SASSI uses what is called a substructure method. In that method, the excavated soil is treated as a separate substructure, and it's separate from the layered half space or free field. And that excavated soil is subtracted, essentially, from the free field to give the impedance of the soil after excavating.

For an embedded structure, there's actually three approaches possible called the subtraction, modified subtraction, and direct method. And they differ in terms of which degrees of freedom are used at interaction nodes. And by "interaction nodes," I mean those nodes that are common to both the free field and to that excavated soil. The nodes on the excavation boundary are connected both to the free field, the excavated soil, and the structure. So, they are all retained.

In the full subtraction method, only the boundary of the excavation is retained. In the modified subtraction method, some of the interaction nodes inside the excavation are retained in the equations of motion. But in the full direct method, all of these nodes are retained in the method, and it's more accurate.

The advantage of using the direct method is, in our case, it's that we do not have to prove that we've used enough nodes within the excavation. Otherwise, you do have to run enough sensitivity analysis to demonstrate that, if you choose to use the modified subtraction, that you've chosen enough interaction nodes.

MEMBER KIRCHNER: Matthew, this is Walt Kirchner again. Sorry to slow you down.

But how far out do you typically have to go in terms of the nodalization to address those issues you just outlined? This is a simplified diagram in front of us, but --

MR. SNYDER: Yes. Well, the direct method requires tens of thousands of nodes, or maybe much more than tens of thousands. But, in our case, I think we had 15 planes of nodes each with many thousands and --

MEMBER KIRCHNER: Okay. Yes. So, this gets back to what I was asking. Given the size of your building and what you would excavate, and so on, I was just curious how many nodes, how far you would go out to accommodate such a large structure in doing the soil-structure interaction. So, you're saying thousands of nodes. So, this is, obviously, just a simplified drawing.

MR. SNYDER: Yes. There are rules we have for the mesh size and all that kind of stuff, based on shear wave velocity.

MEMBER KIRCHNER: Yes, that's what I was kind of getting at with the size and weight, mass of the structure, and such. So, typically, how many meters out from -- say you're building -- I forget what it is. Lengthwise, it's 300-and-something feet long, and, widthwise, it's 100 or so. How far out, when you actually do the nodalization of the soil, do you typically go out? Tens of meters or even further when you do the nodalization for the soil?

MR. SNYDER: Yes, the SASSI model is bounded by the interface of the backfill and the excavated soil in the excavation. So you do not have to -- in the SASSI method, in their substructuring approach, it's essentially calculating the relative motion of this to the free field. So you do not have to put nodes out beyond -- out into the -- beyond the excavation, let's say.

In the past, there have been analyses in which the full soil profile is analyzed by finite elements. And the nomenclature in the past sometimes was that was called the direct method; whereas, this was called the substructure method.

CHAIR RICCARDELLA: So but as I understand it, in this simplified -- in the model at the bottom, the soil library approach would just be to assign an acoustic -- I'm sorry -- a soil impedance to each of those nodes that interface with the building, right?

MR. SNYDER: That's correct. There is no finite element mesh outside of that.

CHAIR RICCARDELLA: Right, right.

MR. SNYDER: So I think the question was how far we would go out for -- for that nodes. It's --

CHAIR RICCARDELLA: But that's to establish what these impedances are, I mean -- right? Once you have the impedances, then you don't need to go outside the excavation.

MR. SNYDER: That's correct.

(Simultaneous speaking.)

MEMBER KIRCHNER: You just put them in at the excavation boundaries then. Got it. All right.

MR. SNYDER: Got it. Yes. And the backfill being modeled by -- it's treated as part of the structure.

CHAIR RICCARDELLA: Yes. And then the

second thing that I read was that you also have to include the seismic vectors in -- from -- it's soil impedances plus seismic vectors. So the seismic vectors, are those, for example, are those like just displacement vectors at each of these nodes, at the interface?

MR. SNYDER: No, they are forces at those nodes that result from a unit control motion.

CHAIR RICCARDELLA: Okay. Okay.

MR. SNYDER: So what we're doing by this is calculating a -- when we do the frequency domain analysis, we're calculating a transfer function that relates the response to a unit input at each frequency.

CHAIR RICCARDELLA: At each frequency, yes. Yes, yes, I understand. Okay. And then you would multiply that times the response spectra at the various frequencies?

MR. SNYDER: You multiply it times the frequency domain control motion --

CHAIR RICCARDELLA: Yes, yes.

MR. SNYDER: -- and they then transform back to the pound. So --

CHAIR RICCARDELLA: If you had this soil library and the seismic response spectra -- the ground response spectra changed, that wouldn't change the soil library because those are all based on unit loads? The seismic vectors are based on unit loads, right?

MR. SNYDER: Yes, it is, but it actually would change the soil library because of the strain levels are calculated based -- so you effectively change the soil -- equivalent linear soil profile.

CHAIR RICCARDELLA: Okay. I understand.

MR. SNYDER: So we have a different one, different library for high-frequency input versus the normal CSDRS.

CHAIR RICCARDELLA: No, but if you had the same soil conditions, but at a different site, say the soil conditions were the same, but the site had a more severe ground response spectra, would that change the soil -- would you have to use two different soil libraries for those two sites?

MR. SNYDER: I would say yes -- the reason is that the strain levels themselves are determined by doing this one-dimensional analysis. It's done using a SHAPE program. And from those strain levels, you assign the properties of the soil layers.

CHAIR RICCARDELLA: I've got it. Okay. I understand.

(Simultaneous speaking.)

MR. SNYDER: -- different site and a different input spectra, you're going to have different strain levels.

CHAIR RICCARDELLA: Yes. Okay. So that's along the lines of the iterative process that Dr. Park mentioned earlier?

MR. SNYDER: Well, yes, I guess it is, yes.

CHAIR RICCARDELLA: Okay. Thank you.

MR. SNYDER: The figure on the right shows the modules used in SASSI. So, you have several paths on the -- within that box labeled SASSI, there's several paths which the SASSI house module is the excavated soil and structure, and the other paths are the free field and the point response within that. So these create stiffness -- or impedance matrices that are assembled in that module labeled SASSI Anal16.

Normally, you would assemble the individual substructure matrices there, and then SASSI would use those in its solution. We're using a customized version of SASSI called SDE-SASSI, and it's been customized so that it writes these matrices and vectors into files. They're written in a standard matrix format. They can be read, that is automatically read by ANSYS itself.

There's one other thing that we do in SDE-SASSI, and that's to reduce these matrices. Since it's the direct method, they normally start with the impedance at all the interior nodes as well as in the boundary. And the interior nodes are eliminated so that we write smaller matrices. The method is mathematically exactly equivalent to the direct method. And that's been verified through the SASSI verification problems, too.

Next slide. Or did we have any more on this one? Hello?

CHAIR RICCARDELLA: Members, are there any questions on this slide before we go on?

MEMBER REMPE: No.

MEMBER KIRCHNER: None from me.

CHAIR RICCARDELLA: Okay. Proceed, Matthew.

MR. SNYDER: Okay. Sometimes I don't know if I've broken up here or what.

Slide 13.

So this shows the ANSYS side of the four library methodology. And I think from our talk, previous talk, you understood how this works in the frequency domain. First of all, we take the soil impedance matrices and rewrite them into the form of ANSYS super elements, as a convenience for importing them into the building substructure.

But that is, again, it's done without customization of the ANSYS program. It's capable of doing that and rewriting without any customization.

The solution in the frequency domain produces the transfer functions for all the frequencies that we use in the soil library. Typically, for a structure this complex, a hundred frequencies would be sufficient in the response analysis, in the harmonic response analysis.

Then that completes the calculation of the transfer functions. Once you have those transfer functions, you can now use any time history input or control motion that correspond to what was assumed in calculating those transfer functions.

And we follow the same process as used in SASSI. The transfer functions need to be interpolated from those hundred frequencies to the thousands that are needed in the time domain or the FFT of the -- or the fast Fourier transform of the time history. So you do have to -- there's ways -- other ways of interpolating. We chose to keep exactly identical to what the SASSI program uses.

And finally for a given control motion, the response in the frequency domain is calculated. That's a simple modification at all frequencies. And then the time domain response from FFT.

Any questions on that one?

CHAIR RICCARDELLA: Okay. Go ahead.

MR. SNYDER: Fourteen. Let's go to 14. All right. I am assuming it's showing now.

Problem 1 is a surface-mounted PWR. That's represented by a stick model and a rigid mass. That problem is a classical SASSI example. It existed back in the seventies, I would suppose. And it has results that compare well to published solutions.

Problem 2 is a simple embedded structure, but it does not have fluid. And then problem 3, we added fluid to compare to. And then, finally, problem 4 is more representative of the NuScale SMR. It's not identical to the design in the DC, but it's close.

For all these comparisons, the problem is solved in two ways. The first way you can do it is to use the building dynamic stiffness from ANSYS and import that back into SASSI. And SDE-SASSI has the ability to import these structural matrices from other programs. And it also has a capability for non-symmetrical equation solution that is needed for fluid-structure interaction. So, effectively, by doing that, we're solving the same equations using SASSI that we would with the ANSYS, and we're verifying that we get the same solution.

Another way of doing comparisons (audio interference) with the soil library method and SASSI is to solve using the SASSI entirely. And what I mean by that is we would use the SASSI house module to get the structural matrices and never use ANSYS in that case. But that second approach cannot be applied in problems 3 and 4 since there's no fluid element in SASSI.

The comparison --

CHAIR RICCARDELLA: So when you made the comparisons for 1 and 2, did that include the ANSYS or the SASSI?

MR. SNYDER: We did it both ways. We did it both ways.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: And to discuss this more, it's in the later session.

CHAIR RICCARDELLA: Okay, okay.

MR. SNYDER: In general, the comparisons are excellent. In fact, you can hardly distinguish most of the curves when you compare using ANSYS versus

SASSI solver. This demonstrates the soil library approach is effectively the same as the SASSI solution, with the SASSI structural matrices, of course, replaced by ANSYS structural matrices.

Any other questions? I'm going to go on to the next one.

CHAIR RICCARDELLA: So you compared acceleration time histories and response, and structural response spectra, at various locations around the models, correct?

MR. SNYDER: That's correct.

CHAIR RICCARDELLA: And forces?

MR. SNYDER: Yes. And for the representative reactor building, we went to the entire -- I mean, we went into the modules, et cetera. So it wasn't just a very limited --

CHAIR RICCARDELLA: Okay.

MR. SNYDER: Next slide, please. Okay. We should be on 15 now.

There were two specific items during the review that we addressed. The first was the addition of the complex -- the original model report did not have problem No. 4. So we added that in response to requests for a more complex -- a demonstration with a more complex problem. And the second comment was a request for additional documentation of the verification and validation of SASSI. Those customizations, in particular, of SDE-SASSI, and we --

CHAIR RICCARDELLA: Yeah, part --

MR. SNYDER: Yes?

CHAIR RICCARDELLA: Part of the RAI requested a more realistic response spectra, too. I guess you used a different response spectra for sample problem 4 than you did in the first three.

MR. SNYDER: No, I think we -- sample problem 4, we used the input CSDRS.

CHAIR RICCARDELLA: Yes, I understand, but I think that was also in response to the RAI, right?

MR. SNYDER: Oh, yeah. Okay. Well, of course, we would use a different one there, too, yes. We wanted to use something more realistic.

CHAIR RICCARDELLA: Mm-hmm.

MR. SNYDER: Okay. Yes. Yes, that's part of the response to the RAI.

CHAIR RICCARDELLA: Okay.

MR. SNYDER: Next slide, please.

In summary, the current methodology provides an accurate and conservative evaluation of seismic loads and demand. The proposed methodology uses a one-step analysis that is functionally equivalent and computationally more efficient. And NRC approval was documented by Safety Evaluation.

That concludes the open part of my presentation.

CHAIR RICCARDELLA: Well, okay. Thank you, Matthew. That was very interesting.

It appears that we're running, oh, maybe about 20 minutes or so ahead of schedule. And so should we -- I'm wondering should we take a break now, Walt, or should we proceed on with the NRC --

MEMBER KIRCHNER: Why don't we proceed on with the NRC staff's presentation?

CHAIR RICCARDELLA: The open presentation. Then maybe take a break before we go to closed session. How's that?

MEMBER KIRCHNER: Yes.

CHAIR RICCARDELLA: Sounds good.

So, Dr. Park, are you ready to make your presentation?

DR. PARK: Yes.

MR. WARD: Okay, I'll -- Sunwoo, if you can put up the slides, and then I'll start the discussion.

DR. PARK: Okay. Just a second, please. Let me share the slide.

MR. WARD: Okay. My name is Bill Ward. I am the Project Manager for this review. I've been a PM in NRO and NRR for a while, and this was an interesting topic to be associated with.

I'd like to thank NuScale for their presentation. And I also would like to thank them for their support in responding to our questions and being patient as we went through this because we did have some turnover in staff as we went through it. But Dr. Park certainly supervised that in the last year (audio interference) the final progress to get this to completion.

So I hope that our presentation here will give you a good overview of how he and the prior reviewers approached this. We did have to do a number of things, including doing an audit on the supporting documentation for this methodology. And that was a little bit of an issue.

But, anyway, so I will turn it over to Dr. Park to begin his discussion.

DR. PARK: Okay. Good afternoon. Yes, my name is Sunwoo Park. I am currently serving as a Reliability and Risk Analyst at the Division of Risk Assessment at NRR. I had been serving as a structural engineer at the Division of Engineering and External

Hazards, NRR, until May this year. And I had been reviewing this Topical Report until the time I was reassigned to the Division of Risk Assessment. And I'm glad to be able to support this Subcommittee meeting in this capacity.

This afternoon, first, I would like to give you a brief introduction to this Topical Report and discuss the regulatory basis and provide some background to the methodology and the corresponding staff review, and discuss more details about a proposed methodology, maybe from a different perspective than NuScale. We are discussing the same thing, but I thought it might be helpful to provide a different perspective from a different angle. And I hope that will help you. And then we will discuss the staff evaluation and discuss the limitations and the conditions that are placed in the Safety Evaluation for this Topical Report, and conclusions.

Again, this Topical Report, as described by NuScale, this provides an improved method for frequency domain analysis of nuclear power plant structures with coupled soil-structure and fluid interaction behaviors, and the method provides an enhanced tool for a nuclear power plant licensee or applicant to calculate seismic risk for the design of structures, systems, and components.

So here we are talking about licensees or applicants, for example, for design certification or combined license, or construction permit, or operating license, so anyone who seeks to submit an application to the NRC for review can use this methodology.

The regulatory basis that staff used in its review includes Part 50 regulation, including Part 50, Appendix A, general design criterion 2 which specifies that structures, systems, and components important to the safety must be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, and floods. Here, we are focusing on the earthquake.

In terms of Part 50, Appendix S specifies that safety functions of SSCs subject to earthquake ground motion must be assured through design, testing, or qualification methods, and the evaluation must take into account soil-structure interaction effects. Here, we note that soil-structure interaction effects are mentioned at the regulation level. And the guidance we used was NUREG-800, SRP Section 3.7.2, on seismic system analysis.

Okay. Let me give you a little bit of background to this -- the Topical Report's approach.

Again, I try to give you -- I try to look at it from staff's point of view.

Okay. Earthquake-induced seismic loads are a major contributor to the design loads for nuclear power plant structures, systems, and components. And the effects of soil-structure interaction are considered in establishing seismic loads for a nuclear power plant built upon a soil site or built in a soil site when the structure is embedded in the ground. So, again here, soil-structure interaction effects must be considered according to the regulation.

The new fluid-filled nuclear power plant designs such as small modular reactors like NuScale and SMR, and other advanced reactors that uses liquid metals for the coolant for the reactor, okay, those designs contain -- they contain fluid, such designs warrant consideration of the effects of soil-structure-fluid interaction in establishing the seismic loads. And no analytical tool currently is available for systematically integrating effects of soil-structure-fluid interaction in developing seismic loads for nuclear power plant SSCs. I captured it here as systematically integrating because there are approximate methods that can account for fluid-structure interaction, but, as NuScale indicated, such approach requires a multi-step analysis, and also it involves a lot of simplification and approximation.

MEMBER KIRCHNER: Sunwoo, this is Walt Kirchner.

On that slide, before you go ahead, on your third bullet, what's different here, obviously, the current fleet of light water reactors are fluid-filled inside the module. What you're really referring to here is that the modules are in a large pool, or at least that's, I think, what's different and new here.

But we've always in the past analyzed the current fleet of LWRs which are liquid-filled/cooled reactors so that fluid aspect had to be considered. It seems to me what's different here is you've got fluid outside of the reactor module as a factor in establishing loads.

DR. PARK: Yes, that's right. In the traditional LWRs, they contain the fluids here and there, also inside of the reactor, but the amount of the fluid or proportions of fluid in terms of a mass compared to the entire structure was very small. And the traditional way of handling the effects of such a fluid in that analysis was using so-called lumped mass approach --

MEMBER KIRCHNER: Right.

DR. PARK: -- which is approximate. But in the new design, like a NuScale SMR and the other domestic reactors using liquid metals, the relative proportion of the mass of liquids are quite significant compared to the traditional LWRs.

MEMBER KIRCHNER: Right, right. So that was my point. My point is that what's really different here, just say hypothetically or rhetorically, if the reactor building with the 12 modules was not filled with water because it's the ultimate heat sink, then we would have a fairly classical analysis like the existing fleet, where the fluid inside of the vessel, as you say, could be treated as a lumped mass.

And given the structure inside of the vessel, it's not quite the same as having what I'll describe as a free field of fluid, a swimming pool. That's a different thing altogether from existing plants, notwithstanding the spent fuel pools.

CHAIR RICCARDELLA: I think -- you know, Sunwoo, you can correct me if I'm wrong, it's the quantity of water. There's sufficient water in this design that it can feed back to the structural movement versus --

MEMBER KIRCHNER: Yes. No, that's my point. Yes, exactly.

CHAIR RICCARDELLA: -- in a classic PWR, the system, I mean you have to consider the interaction with the fuel and things like that, but it's not going to feed back to the --

MEMBER KIRCHNER: Yes, precisely.

CHAIR RICCARDELLA: -- structural response spectra.

MEMBER KIRCHNER: Yes.

DR. PARK: Yes.

CHAIR RICCARDELLA: Sunwoo, is that also true, for example, of BWRs that have the big suppression pools?

DR. PARK: Yes. Still, the amount of the waters in the BWR or PWR are relatively small compared to, for example, NuScale. NuScale's pool, the amount of the water is significant, and the staff recognized that the presence of such a huge water mass will alter the dynamic characteristics of the entire system.

CHAIR RICCARDELLA: Mm-hmm.

DR. PARK: So, traditionally, the lumped mass approach which is used by SASSI is not appropriate because it will give a very rough estimate. So that's why this new approach is proposed.

CHAIR RICCARDELLA: Okay.

DR. PARK: Okay. Okay. And soil-structure interaction analysis is typically performed using the SASSI computer code. Here, SASSI is an acronym for a System for Analysis of Soil-Structure Interaction. And the analysis code was originally developed at the University of Texas -- I mean University of California, I'm sorry, Berkeley, in 1981. And since then the SASSI code has been used widely in the community, particularly in the nuclear industry.

However, SASSI does not have the capability to effectively handle fluid-structure interaction. As I explained it just a minute ago, it can only handle it in a very crude and approximate manner. And fluid-structure interaction analysis can be performed using a finite element analysis code such as ANSYS, which is a general purpose finite elements analysis code, which is, again, widely accepted by the engineering community across the board.

However, ANSYS does not have the capability to effectively handle soil-structure interaction. Yes, that's the limitation, and I know there is an attempt to handle the soil-structure interaction problem using the general purpose computer code like ANSYS. And I understand those efforts are still in a research stage, and more evaluation is needed to be accepted.

The Topical Report proposes a methodology that integrates the capabilities of SASSI and ANSYS to handle soil-structure-fluid interaction during the earthquake.

We are on slide 8, for those of you who may be joining audio only.

The elements of the proposed methodology consist of substructures that represent interacting entities involved in the analysis, which are the soil substructure, building substructure, and the fluid substructure. And these substructures collectively represent a coupled soil-structure-fluid interactive system that is analyzed for a prescribed earthquake ground motion.

And the different substructures representing different site soil conditions can be created and stored, and an integrated analysis can be performed for each different soil substructure without impacting the other substructures. That's what the soil library method is all about.

Okay. Let's look at the assumptions that the Applicant placed and included in this Topical Report. The proposed methodology is based on the following three assumptions.

The first one is about the material properties, which are deemed elastic during the analysis. And the second assumption pertains to the linearity of ground conditions and their constraints. And the third assumption addresses the seismic load being represented by vertically propagating shear and compressive seismic waves.

And staff reviewed and determined that these Applicant assumptions on the linearity of the material properties, linearity and boundary conditions, and the constraints, and the seismic load, represented by vertically propagating seismic waves, are all consistent with the established state of the practice in soil-structure interaction analysis of nuclear structures, and also with the provisions of the American Society of Civil Engineers, ASCE, Standard 4-16.

Yes, the staff has reviewed soil-structure analysis and they are presented as part of different applications for the past years. And we have observed that these assumptions are quite common among the different soil-structure interaction analyses which is based on SASSI methodology.

And also, staff noted that the site-specific considerations may invalidate the applicability of any of these assumptions for a particular analysis. So, accordingly, the staff finds these assumptions to be acceptable, provided that each of these assumptions is a condition and a limitation on the applicability of the Topical Report for any particular analysis, and that the related -- and limitations and the conditions section of the staff's Safety Evaluation. Staff viewed that, since the proposed methodology is based upon these assumptions, it is natural that these assumptions be captured in the conditions and the limitations section of the SE.

MEMBER KIRCHNER: So, Sunwoo, this is Walt Kirchner.

Could you give an example for the public of site-specific conditions that would invalidate these assumptions? I can make some things up, but this isn't my field. So what would be an example of a site that would be unsuitable for assuming that the linearity of material properties, boundary conditions, and seismic load is represented by a vertically propagating wave?

DR. PARK: I believe, for example, the combined license application that provided soil-structure interaction analysis, their analysis will be based upon these very assumptions that they captured in the Topical Report. But, however -- and, of course, linearities are there and the actual real-world conditions are all -- linear, but --

MEMBER KIRCHNER: No, I guess what I was saying was what are some examples of sites where the linearity assumptions would not be valid? And therefore, if an applicant wanted to use that site, this methodology would have to be enhanced or modified, or so on.

DR. PARK: The staff expects that the applicant, for example, for combined license, using this Topical Report methodology, they address what was the conditions or assumptions that their analysis is based. For example, the soil linearity, if they correctly address the way to address soil linearity properties, for example, using an equivalent linear approach, then they use this methodology, that is acceptable.

And also, for example, there is a situation which causes linearity, for example, soil-structure saturation during the earthquake, the saturation between the building and the surrounding soil, and also, uplift and the sliding, and those all --

MEMBER KIRCHNER: Right.

DR. PARK: -- are typical of the linearity conditions. And without addressing those linearities in their application --

MR. COLACCINO: Sunwoo, if I could interrupt here, this is Joe Colaccino. I'm Chief of the Structural and Geotechnical Engineering Branch.

And if I understood the member's question correctly, he would like an example of where this methodology could not be used.

Is that correct, sir?

MEMBER KIRCHNER: Yes, sir. Your logo looks to show something that might be unstable under seismic load.

MR. COLACCINO: It's very stable, although I think it's called delicate arch.

MEMBER KIRCHNER: It is. It's a delicate arch. I recognize it. Okay.

(Laughter.)

MR. WARD: This is Bill Ward. I would like to add earlier --

(Simultaneous speaking.)

MR. COLACCINO: Bill, if I could finish, please?

MR. WARD: Oh, I thought you were done.

MR. COLACCINO: No, sir, I'm not. Thank you. I know this is kind of challenging, but we're all getting used to this now.

And if Sunwoo does not have an example right now that he could give where this would not be applicable, we would be happy to come back with that.

DR. PARK: No, I gave, I was giving an example.

MR. COLACCINO: Yes. I --

DR. PARK: For example, soil-structure saturation. And as for the applicant to address those, the aspects, and then they propose to use the equivalent linear elastic or the equivalent linear assumption then, and they use this methodology, it will be acceptable.

So I would say there's some certain level of technicalities is involved here because any application of this methodology should satisfy the assumptions.

MEMBER KIRCHNER: No, I understand that, Sunwoo. No, let me give you an example of what I'm thinking about.

So I already pointed out earlier this is a rather large structure, the reactor building for NuScale with 12 modules. And so say you went to a site and you excavated, and you didn't get the nice, clean excavation of the nodal diagram that was shown earlier; that you really had to take away a lot of material, and you had to put a lot of backfill in place to kind of secure the structure in the excavated situation that it's built. Do things like that, then, kind of invalidate the linear elastic assumptions because you don't have the tight coupling with the soil that you have if you get a perfect excavation and you put the concrete right in, and you fill the -- you know, you just do it perfectly?

Say you had to put in tens of yards of backfill on all sides of the concrete foundation. Then do you get yourself into a situation where the linear elastic, both the soil, the coupling with the structure, and such, invalidate this method? That's where I was going with my question.

DR. PARK: Well, yes, in such a case of backfill surrounding the structure, those backfill materials can be modeled as a part of the structure in the SASSI methodology, and that approach is acceptable.

And as to the material properties for backfill, of course, it's -- non-linear in nature, but, again, if the applicant is going through some, for example, strain-dependent analysis, we credit the analysis, and then, come up with equivalent -- conservative equivalent to linear elastic properties, and then apply this methodology, you know, Topical Report methodology, that is acceptable. But what I'm referring to is that without such explanation or addressing those issues, and then apply this, may not be acceptable. But we, as a staff, expect that applicants, they will address -- they will apply this methodology with such a proper explanation.

So, we don't expect that there will be a lot of cases that eventually invalidate these assumptions, but, again, from linearity to linearity, the conversion is needed before they can apply this methodology.

CHAIR RICCARDELLA: This is Pete Riccardella.

I would think that there would be some checks you can do after the fact to demonstrate that the analysis is, that the linear assumptions are, in fact, applicable, some tests, you could say. For example, it was mentioned that, well, the soil impedance will depend to some extent on the accelerations that are produced and the strains that are produced in the soil. Well, once you finish the analysis, you can go back and look at the maximum strains and make sure they didn't violate the assumptions that went into producing those soil impedances.

DR. PARK: Yes, in the case of the strain-dependent soil property analysis, that's I think in a separate space. Eventually, the applicant will end up getting the conversion stiffness for soil to that process. Again here, this condition and the limitation may not be a very limiting, the conditions and the limitation, in a practical sense, as long as the applicant provides a good explanation before they apply the site-specific condition to this Topical Report methodology.

MR. PARKER: This is Josh Parker at NuScale. Can everyone hear me?

DR. PARK: Sure, I can hear you.

MR. PARKER: All right. I want to chime in a little bit here and maybe mention a couple of things.

The one check that we do do to ensure linearity is, for example, the percentage of the foundation in contact with the soil. So, we do look at, for example, if there's an uplift. That would be an example of a check that's done to ensure that we have sufficient percentage of the foundation in contact with the soil or that the building hasn't uplifted. And so, we would do that check just like we would in the previous approach.

CHAIR RICCARDELLA: Yes, I understand that. Thank you, Josh.

MR. PARKER: Yes.

CHAIR RICCARDELLA: Those are the kinds of things I was asking about.

MEMBER KIRCHNER: I was thinking the same thing, Pete. You know, when would you get slippage?

CHAIR RICCARDELLA: Right.

MEMBER KIRCHNER: How much contact with the -- you know, you excavated, and then, you put your foundation down. That's why I raised the example of a lot of backfill all around. Then, you would be dependent on -- and again, this is not my field -- but I would think you would be dependent on the foundation, the base mat contact with intact soil, so to speak. So that, then, the transfer of functions from the soil to the structure are first-order realistic of the soil samples that you use to determine the impedance and all the other characteristics.

CHAIR RICCARDELLA: What about --

MR. PARKER: There's one aspect that I wanted to clarify what was said earlier. I think you hit on this, Walt, and Sunwoo I think answered it also. But, to reiterate, the size of the model really isn't a limitation; and thus, the size or amount of backfill isn't a limitation for us. That's one of the nice things about this, is that we're not limited to total numbers of nodes or elements like we were previously with SASSI. And so, we can expand our backfill as needed or we can expand our overall excavation as needed to encompass whatever site conditions we might have.

MEMBER KIRCHNER: Okay. Yes, that's what I was trying to explore. We had the nice, neat nodal diagram, but if you don't actually get a clean excavation and you wind up with a lot of backfill, et cetera, et cetera, how valid is the model, and so on?

CHAIR RICCARDELLA: Doesn't the backfill just become part of the soil, then, and you treat it as part of the soil?

MEMBER KIRCHNER: Yes, yes. You would have to nodalize for that.

CHAIR RICCARDELLA: Yes.

MEMBER KIRCHNER: Because if you're in rock and you're using backfill, the impedance of the backfill is going to be different than the rock.

CHAIR RICCARDELLA: Yes.

MR. PARKER: And that's part of the structural model. Our model includes the buildings, the modules, the water inside, but, then, also includes solid elements to represent the backfill. And so, we have the fill conditions as a part of the solid elements. That's all in the structural model.

MEMBER KIRCHNER: Okay. Thank you. Thank you.

CHAIR RICCARDELLA: So, I'd like to ask a question about the non-linearity of the fluid interaction and how to address that. And it brings to mind, I happened to live in San Jose, California in 1989 at the time of the Loma Prieta earthquake. And my daughter was on the high school swimming team during that earthquake. They were practicing. And there was so much sloshing that went on in that pool, that some kids were actually picked up out of the water and set on the deck.

If some situation like that were occurring in the pool, would that be covered by this fluid-structure interaction effect analysis?

DR. PARK: Yes. Again --

MR. PARKER: We might cover that in the closed. Sorry to jump in on you, Sunwoo.

CHAIR RICCARDELLA: Okay. That's fine.

MR. PARKER: We might cover that a little bit during the example problems in the closed session.

CHAIR RICCARDELLA: Okay.

MR. PARKER: We can talk about what we do with the fluid elements. Matthew touched on that in his presentation, but we can maybe talk more about it there, if we need to.

CHAIR RICCARDELLA: Okay. That's fine. I'll defer the question until the closed presentation. Thank you.

MEMBER KIRCHNER: I could second that, Pete. I was on the NS Savannah, and it had nothing to do that it was a nuclear-powered ship. But we often were swimming in the swimming pool on the upper deck. And if you got into a good sea swell and were pitching back and forth, you could get pitched out of the swimming pool right up on the deck from the sloshing effect. It was very non-linear.

CHAIR RICCARDELLA: Okay.

So, Sunwoo, go ahead.

DR. PARK: Yes. Again, this methodology that is proposed by NuScale is frequency domain analysis. And the frequency domain analysis is limited to a linear problem because of the nature. Because a frequency domain analysis is built upon the concept of superposition of many different -- how many motions.

And so, that includes the linearity of the soil substructure and the building substructure, and the fluid substructure as well. But I believe that there would be a way to the linearization of those fluid behavior, that, that involves some of the splashing and the linear behavior. So, as long as we can get a good linear approximation to this linear behavior, maybe this methodology can still be applicable.

Okay. Let me move on to the next topic, which is computer codes. There are two computer codes that were used in the development and evaluation of the proposed methodology by the Applicant, which included ANSYS, Version 18.1, and SDE SASSI, Version 2.1.

The ANSYS code, again, is a well-recognized program which has been widely scrutinized and evaluated by the engineering community and the finite elements engineering community. And also, the NRC's past experience is that the results obtained from ANSYS have been acceptable. Specifically, SRP 3.8, which describes the design of structures, the applicant typically used ANSYS for such a purpose. So, ANSYS, therefore, as it's used in the TR can be accepted without further evaluation.

MEMBER MARCH-LEUBA: oh, hold on. Hold on. Can you go back a few slides? This is Jose.

DR. PARK: Sure.

MEMBER MARCH-LEUBA: I would agree that ANSYS has been validated and benchmarked and it's an excellent code. But the important thing to review is not the code itself, but the methodology to produce input decks into ANSYS. I mean, the fact that the code is acceptable, have you reviewed the way the input parameters to ANSYS are produced? And are those properly defined?

DR. PARK: We focused on how the soil library is transported or exported into ANSYS by reviewing the information provided in the TR. And we found that that workflow is good and also --

MEMBER MARCH-LEUBA: So, you have reviewed the workflow and verified it and checked it with RAIs and audits, and figured out that there are no mistakes on that?

DR. PARK: We haven't had an audit yet, an audit for checking the actual input deck that they used. Our audit conducted included only the scope of validation of the software, which is SDE-SASSI, which I am going to give more detail in a later slide. But we haven't checked the actual input deck that the Applicant used in producing the results.

MR. WARD: If I can add something? This is Bill Ward.

I know Sunwoo and the prior reviewers did look at the process, the inversion of matrices, and all that, the math behind everything, and ensuring that the connection between SASSI and ANSYS was logical and the manipulations that were done to the datasets were appropriate.

DR. PARK: Yes, those mathematical, the operations or manipulations that are involved in developing methodology, but whether the staff reviewed the input deck, that part, we didn't go that far. But, again, the demonstration problems provide the evidence that such input process must be good; otherwise, the comparison of the results from the different workflow would not agree.

MEMBER MARCH-LEUBA: Yes. My example, I

mean, let's have just a calculator which is a pretty good calculation, and if you put 2 plus 2, it comes out with 4. But, if with my finger I put 2 plus 3, it comes out with an answer of 5, which is incorrect because I wanted 2 plus 2.

So, what we are proving is not the ANSYS code we know is good. I mean it's been used for many, many years, validated many, many times. What we are reviewing is the methodology that produces the input to ANSYS. That was my point. I hope you guys have looked at that.

DR. PARK: Yes, that part the staff has closely reviewed because that was the key to this improved methodology which involves the soil library concept. Yes, staff reviewed that part.

MEMBER MARCH-LEUBA: Okay. Thank you.

DR. PARK: Okay. Now, SDE-SASSI, Version 2.1, the staff reviewed the Acceptance Testing Report OSD SASSI code used in the development and the evaluation of the proposed methodology, and then, we determined that the use of the code is acceptable because of the following:

First, we identified that the selected test problems is adequate because the range of input parameters considered in these test problems covers the range of input parameters expected in the application of the analysis methodology proposed in the TR. Because if the input parameters are not, if the range of input parameters are not properly tested through testing problems, then you may not have a full confidence of the range of applicability of the methodology. So, we thought that was an important aspect of that validation.

And the methods of modeling and analysis employed for the test problems conform to the guidelines in NUREG SRP Section 3.7.2. And the solutions from SDE SASSI are comparable with the benchmark solutions from the established theory and the numerical methods, including quotes from the solutions published in the literature and, also, the numerical methods which have been accepted.

MEMBER MARCH-LEUBA: One final question. For the previous methodology, the one before today, we were using those seven different methods and models and coupling them together and getting a solution. And now, we have a single model that produces a solution. Have you guys compared before and after? Is there any difference between the two evaluation methods? Obviously, there's a difference. Any significant difference between the two methods for

NuScale?

DR. PARK: Yes, maybe that goes to the example problems review. But, anyway, we have reviewed the example problems and the solutions, and there were conclusions that NuScale has acquired from their own evaluation and represented in the TR. There are multiple levels of validation. The first validation is validation of a soil library in concept and in implementation. And that was done by comparing results from traditional SASSI methodology. That's No. 1.

And then, No. 2 is this soil library methodology implemented in ANSYS and those results, results from totally traditional SASSI methodology, and then, the ANSYS-implemented soil library methodology. The results are very comparable. They really are, which provides evidence that the soil library, both concept and implementation, are adequate.

Now, based on that, the next step is the validation of expansion of this soil library, the concept, to include fluid-structure interaction. So, the soil-structure-fluid interaction, the analysis, that's the ultimate goal of this proposed methodology.

Now we know that there is no existing

solution that it can be compared against to test the NuScale-proposed soil library methodology expanded to the soil-structure-fluid interaction. Now the question was whether the staff had an opportunity to compare the results from this new methodology, one step, the one-step approach, with, say, results presented in the DCA which was based upon the multi-step approaches.

We didn't have that comparison because the analysis of cases and, also -- they are not exactly the same conditions, analysis conditions. For example, in the DCA analysis, the input control motion was a place at the bottom of a base mat; whereas, in the example 4 of the Topical Report, the control motion was a place at the ground surface. And also, in the DCA, the results that the staff has enveloped the results, which is used as the design basis. And that enveloping process involves a very large number of analysis compared to a single-case analysis from example 4.

So, for those reasons, there is no opportunity for a one-on-one comparison between this one-step, new methodology and all the multi-step methodology for soil-structure-fluid interaction. I think that's what NuScale also explained early on when they explained about the example 4.

MEMBER MARCH-LEUBA: So, your engineering judgment is that the original multi-step seven-model methodology was very conservative, and the new methodology with a single step is still conservative?

DR. PARK: Yes, my opinion, based on experience, and, also, based on because I was also reviewing the NuScale design certification and application, Section 3.7.2, in the DCA, since this single-step, integrated approach was not available, the Applicant used the multi-step. And, also, the conservatism was included in their approximation, because that's also the staff's expectation because, when there is an unknown, then that should be reflected through conservative assumptions. And so, based on that, I believe this new methodology will produce much more accurate and realistic outcome without unnecessary conservatism involved there.

MEMBER MARCH-LEUBA: Okay. Thank you.

DR. PARK: You are welcome.

Any other questions?

MEMBER KIRCHNER: Yes, Sunwoo. This is Walt Kirchner.

I would have addressed my colleague Jose's earlier question by saying, comparing the first two example problems, where the agreement -- I mean, the better part of the TR is just filled with graphs showing comparisons of the different methods against the four example problems. And the comparison is quite good.

So, I think you're right, Jose. In terms of application, it's, then, the staff would really have to audit the input models, given that the codes themselves have at least shown good behavior. You know, within the range of applicability, they calculate the kind of theoretical and other benchmark numerical examples. But, then, when it comes to the actual application, then I would think it would be incumbent on the staff to audit the COLA applicant model that was used for the actual seismic analysis.

DR. PARK: Yes, definitely. Yes. Yes. I think so, yes. We expect that we will conduct much more comprehensive review, including the audit activity, when we review a COL application which uses this particular methodology.

Okay. Let me move on to the next slide, which is slide 14.

Okay. The solution flow, the filing summarizes the solution flow for an integrated analysis of a seismic substructure fluid interaction proposed in the TR. Again, NuScale, they presented their workflow or methodology, and this is our view of the understanding. And they may be representing the methodology, maybe using maybe different language or maybe from a different perspective. But I guess we are talking about the same methodology.

The step 1 involves the modeling substructure in SASSI modeling. So, it's substructure and the derivation of the parameters necessary to capture the seismic soil-structure interaction effects. And these parameters included soil impedances and seismic load vectors, two things. And they are stored in the soil library, which can be exported into ANSYS.

Also, this soil library is a newly-coined term, coined by the Applicant, I would say. So, it's a creative way of rearranging the established SASSI methodology. In SASSI, there are many different analysis modules. And then, NuScale, they combined different modules which are already available in SASSI to come up with this soil library concept, which can be exported into ANSYS. So that ANSYS can handle soil-structure interaction. Remember, I said that ANSYS cannot effectively handle the soil-structure interaction problem because that transcended the regular finite element method which involves the functions, the method for analyzing the soil impedance matrix and dealing with infinite lateral extent of soil layers and so on, and, also, radiation damping issues, and so on. So, for those reasons, traditional finite element totally cannot effectively handle soil-structure interaction, but SASSI does, because SASSI is exactly, was created to handle those purposes.

Okay. Step 1 is that soil library, and step 2 in ANSYS, model building substructure and fluid substructure using appropriate structural and acoustic elements that capture the fluid-structure interaction effects. Yet, I guess any regular finite element code can handle these aspects. There is nothing special for this.

In step 3, in ANSYS, integrate the effects of soil-structure interaction, which is imported through the soil library from SASSI, and the fluid-structure interaction effects from using ANSYS's only finite elements. And then, solve the resulting equations of a motion to determine the seismic loads for SSCs, fully accounting for these soil-structure-fluid interaction effects.

So, I tried to give a picture as to how SASSI and ANSYS are involved and what their roles are, and so on.

Staff reviewed the information on the Applicant's solution workflow for frequency domain soil-structure-fluid interaction analysis and finds them acceptable because soil-structure interaction parameters contained in the soil library are derived within the framework of the established SASSI methodology, and the building and the fluid substructures, and fluid-structure interaction effects are analytically modeled using the established ANSYS structural and acoustic elements.

And the modeling and the analytical procedures involved in the proposed workflow, they conform to the guidelines of SRP 3.7.2. And the adequacy of the solution workflow is further validated through the example problems presented in the Topical Report.

The TR also describes certain enhancements to the established SASSI methodology which were applied to the proposed methodology. In the previous slide, I explained that the Applicant used or came up with the soil library, the idea, within the framework of established SASSI methodology. Now they proposed certain enhancements to the established SASSI methodology, which is a new thing that they came up with or they developed for efficiency.

Okay. For efficiency here, the soil library can be compressed in size through the condensation of internal soil degrees-of-freedom. It's a bit technical, the language used here. So, basically, they, NuScale, came up with the idea, this idea of a condensation for the purpose of compressing the size of the soil library through certain legitimate process which involves eliminating soil degrees-of-freedom at the nodes which are interior to the excavated soil volume and only retaining those degrees-of-freedom at the nodes along the soil-structure interface. You can do that through the condensation, which involves metrics operation.

And the staff reviewed that process and they followed the established mathematical principles in doing such an operation. And SDE-SASSI has the ability to solve an SSI problem using an ANSYS substructure containing the fluid-structure interaction.

Okay. Normally, you use ANSYS's solver to solve the soil-structure interaction problem. But they improved their SASSI code, which is the SDE-SASSI, in such a way that it can solve the equations which contain soil-structure-fluid interaction effects, and then, compare the solution to those solved using ANSYS as the solver. Okay.

And before doing that, they have to do the third bullet. SDE-SASSI has the ability to solve equations with non-symmetric mass and stiffness matrices associated with fluid-structure interaction problems. The fluid-structure interaction results in non-symmetric matrices and the traditional SASSI can handle only symmetric equations. Now the SDE-SASSI has that ability to handle non-symmetric equations.

Staff reviewed the enhanced solution features, and they are acceptable because the mathematical operations involved in developing the enhanced features conform to the established mathematical principles, and the equations and the parameters used in the enhanced features are consistent with the established principles and dynamics of the structures.

So, the first bullet belongs to the mathematical, the correctness. And the second one belongs to the mechanics point of view, correct from the mechanics point of view. And the third, the validity of the enhanced features is demonstrated through example problems.

The staff reviewed specifically each of

those enhancements. For example, condensation, we reviewed the results from condensed equation versus an uncondensed, the uncondensed soil library, full-size soil library, and those results agreed. And also, those method equations.

We reviewed the results from SASSI and ANSYS. ANSYS has this intrinsic capability to handle non-symmetric equations. And then, SDE-SASSI is improved to have that capability. And we evaluated, we confirmed the results from both the software, agreeing that they pretty much are matching each other.

Example problems, I think I don't have to repeat the description of a problem because NuScale has already introduced those four problems.

Okay. Problem 4, again, it was added in response to staff's request for additional information, which provides a more detailed comparison of an SMR-type building.

Staff reviewed the example problems and the results provided in the TR and found it compelling. Staff observed that the results from example problems supported the adequacy of the proposed soil library approach to solving the soil-structure-fluid interaction problem. And the staff identified a good agreement that results from ANSYS and SDE-SASSI, which supported the validity of the proposed workflow and the enhanced solution features, including non-symmetric equation software and so on, and condensation.

Staff concludes that the example problems in the TR provide evidence that the proposed frequency domain, also the fluid interaction analysis methodology is adequate.

The limitations and the conditions I think we discussed early on. Again, staff thought that it is prudent that these assumptions be captured in the form of limitations and the conditions. Again, the staff's expectation is that combined license applicants will still be able to apply this new methodology proposed in the TR without much problem, as long as they address and they explain how they in real linearity can be linearized, and then applied as the linearity-based TR methodology.

So, NRC staff has completed its review of this TR, and they conclude that, subject to the limitations and the conditions as specified in Section 6 of the staff's Safety Evaluation, the frequency domain analysis methodology described in this Topical Report is acceptable to perform seismic soil-structure-fluid interaction analysis to establish the seismic demands for the seismic qualification of structures, systems, and components in compliance with the guidance in NUREG-800, SRP Section 3.7.2, and thus, in compliance with the applicable regulatory requirements delineated in Section 2 of the staff's Safety Evaluation.

Yes, I think that's pretty much about it. And I just developed one slide here which may assist you in better understanding the soil-structure-fluid interaction concept. So, if I may spend just a couple of minutes, I can explain this. Otherwise, I can just pass.

CHAIR RICCARDELLA: Okay. We are getting relatively short on time, Sunwoo. So, if you would just try to go through this quickly because we want to have time for a break, and then, have some significant discussion of the sample problems during our closed session.

DR. PARK: Okay. Yes, then, okay, quickly, the cartoon on the right top represents a structure sitting on a rock subjected to earthquake. So, in this case, the analysis requires just the standard dynamic structure analysis, which is also called a fixed-base analysis.

And the second case is a structure sitting on soil subjected to earthquake. Then, we need a soil-structure interaction analysis.

And the third situation is a fluid-filled structure sitting on rock. You only need to address fluid-structure interaction because there is no soil-structure interaction involved here.

And the last case involves all full interaction among soil, structure, and the fluid, which is the focus of this Topical Report.

With that, any questions that I can address?

(No response.)

CHAIR RICCARDELLA: Well, thank you for the thorough presentation, Sunwoo. I think --

MR. WARD: If I may add something? This is Bill Ward.

CHAIR RICCARDELLA: Sure.

MR. WARD: Yes, we wanted to make clear that this Topical Report was submitted in support of the standard design approval application for the 720 design, the 60-megawatts-per-module design, that is expected to be submitted soon. It was in support of the design certification that essentially completed the review.

CHAIR RICCARDELLA: Yes. Yes, I understand that. And I think we just would like to make a comment. You know, we just went through a session with the ACRS where we identified lessons learned from our review of the NuScale DCA. And one of our lessons learned had to do with timeliness of Topical Reports. And I'd like to acknowledge that this Topical Report timing has come in well in advance of the actual use of this methodology. So, I think that's moving in the direction that we were hoping.

With that, are there any further questions or comments by members? Or would you rather wait until after we have the closed session?

MEMBER KIRCHNER: Pete, this is Walt. Just a quick comment.

Thank you, NuScale and Staff, for doing an extensive open presentation. That's valuable for our process, and I thank you for doing that.

CHAIR RICCARDELLA: Do any other members wish to make a comment at this time?

(No response.)

No? Then, I think since this will be the end of the open session, we should open the line, the public line, and see if there are any public comments.

Could someone confirm that, please?

OPERATOR: The public bridge line is open for comments.

CHAIR RICCARDELLA: Okay. So, is there anybody out there in the public that would like to make a comment on these last two presentations on this new seismic methodology?

(No response.)

Is there anybody out there at all? Just acknowledge that you're there, so we know that the line is open.

(No response.)

I guess we did not have a lot of public interest.

OPERATOR: The line is open.

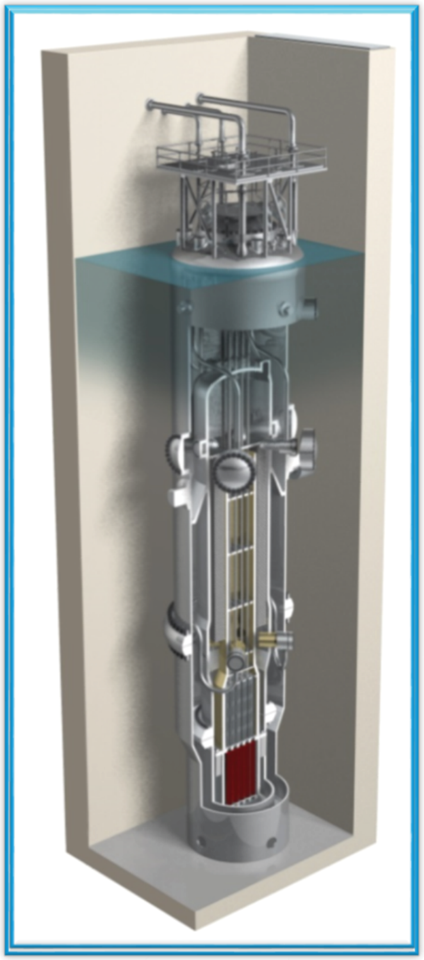
CHAIR RICCARDELLA: Okay. The line is open.

So, with that, we will take a 15-minute break, and then, reconvene -- I guess we're closing this session and we will open the new, private, closed session. And I believe everybody who needs to has received an invitation for the closed session.

It's now 4:25 Eastern Time. So, we'll reconvene on the closed session at 4:40 Eastern Time. Okay?

(Whereupon, the above-entitled matter went off the record at 4:25 p.m.)

ACRS Subcommittee Presentation



NuScale Topical Report

Improvements in Frequency Domain Soil-Structure-Fluid Interaction Analysis

September 22, 2020

PM-0920-71643
Revision: 0

Template #: 0000-21727-F01 R6

Presenters

Matthew Snyder
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Agenda

- Purpose
- Features of Methodology
- Applications
- Background
- Soil Library Methodology
- Topical Report Demonstration Problems
- Topical Report Review
- Summary

Purpose

- The Frequency Domain Soil-Structure-Fluid Interaction Analysis topical report (Soil Library TR) describes a more efficient process, for use by an applicant or licensee, to perform seismic analyses of complex, interacting structures, soils, fluid systems, and major mechanical components.

Features of the Soil Library Methodology

- Eliminates assumptions at the interfaces between the civil structural and substructure analyses (single model vs. seven different models)
- Single larger model can be used for seismic and nonseismic loading
- Major improvement in runtimes to generate analysis results
- Simpler method
- Facilitates parametric studies for alternate module configurations (any number of module in any location)
- Uses latest finite element technologies and improvements
- Provides additional element formulations that are not in older codes such as SASSI

Applications

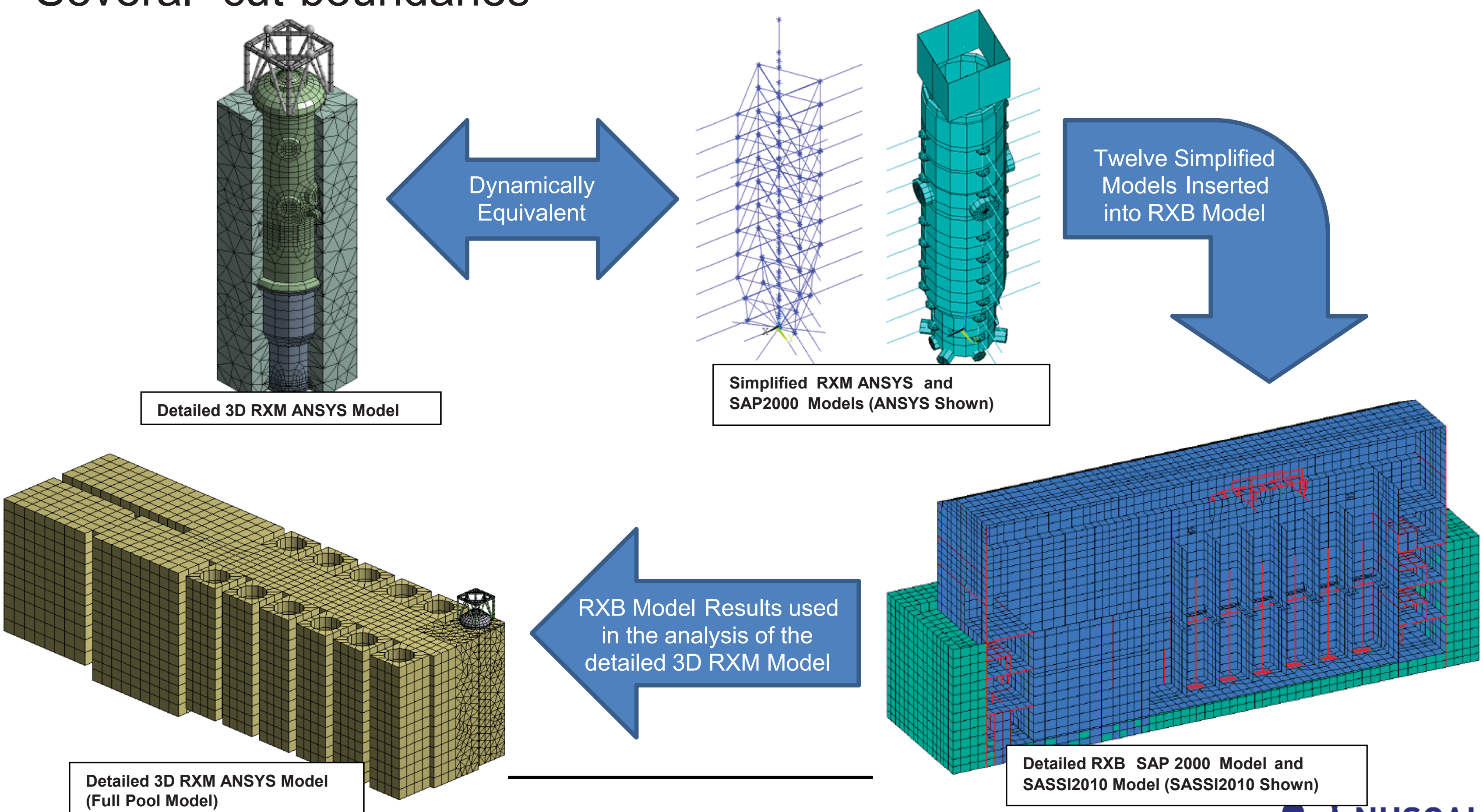
- Analysis of Detailed Design Certification Applications and Standard Design Approval Applications
- Site Specific Combined License (COL) Analyses
  - Site specific soil library generation for Combined Licenses
  - Evaluation of adequacy of NuScale design as specified in existing COL Items using proposed methodology

Background

- Current seismic analysis methodology
  - provides an accurate and conservative evaluation of seismic loads/demand
  - Conforms to NRC regulatory guidelines
  - Uses multi-step dynamic analysis for SSI analysis of building and subsequent detailed analysis of substructures

Background

- Time history method is used for evaluating non-linear behavior (e.g. module liftoff at skirt support)
- Several “cut-boundaries”



Soil Library Methodology

- Eliminates two-step analysis process
  - Analysis using single structural model of building, backfill, pool water, and individual power modules
  - Simplifies data exchange and interfacing analyses
- Analysis time shorter by order of magnitude
- Takes full advantage of structural analysis capabilities of ANSYS
  - Overcomes limitations of SASSI structural model size and mesh refinement

Soil Library Methodology

- Proposed methodology in Topical Report
  - Use of a SASSI calculated impedance library
  - No change to seismic inputs and soil properties.
  - Revision to the basic assumptions and methodology for SSI analysis
    - Uses SASSI direct method versus modified subtraction method
  - The replacement of the SASSI building model with an integrated ANSYS model, and using the ANSYS solver
  - Dynamic analysis for SSI is functionally the same as SASSI

Soil Library Methodology

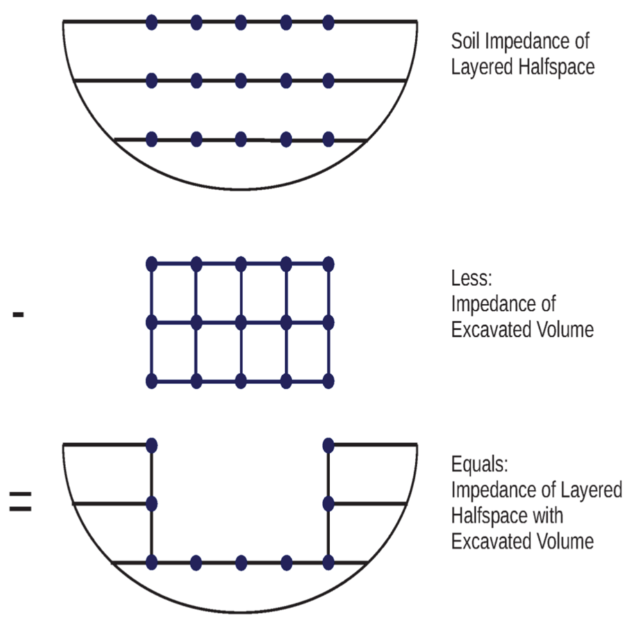
- Dynamic Analysis performed in the frequency domain
  – Soil impedance from SASSI + ANSYS structural model + ANSYS equation solver and post-processing
- Validated using example problems
  – Demonstrates equivalent results from traditional SASSI versus the library method
- Methodology assumes linear elastic or equivalent linear-elastic analysis
  – This applies to both soil and structural properties, constraints, and boundary conditions
- Uses one-step dynamic analysis for SSFI of buildings, RXMs, and pool water
  – Saving of overall analysis calendar time
  – Seismic analysis methods of secondary SSCs and fuel unchanged

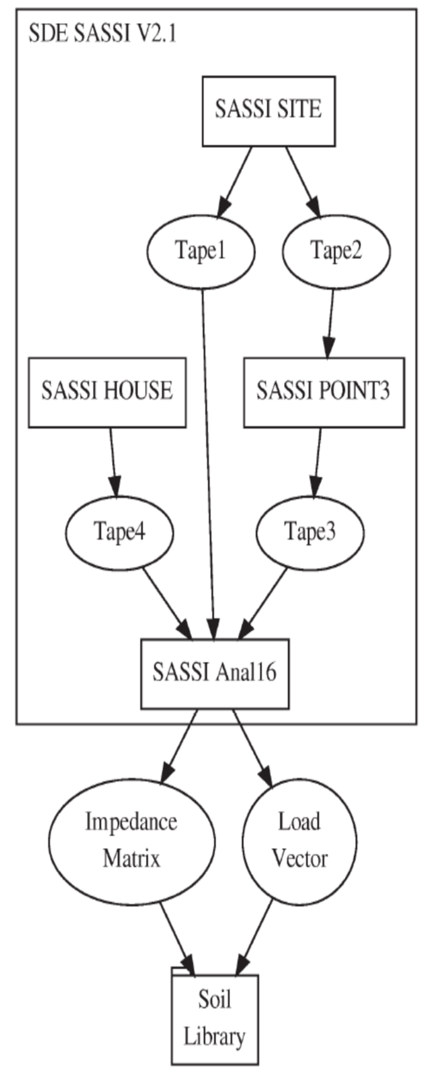
Soil Library Methodology

SASSI Direct method

Matrix reduction

Soil impedance/load vectors calculated by SASSI Anal16 and exported in Matrix Market format

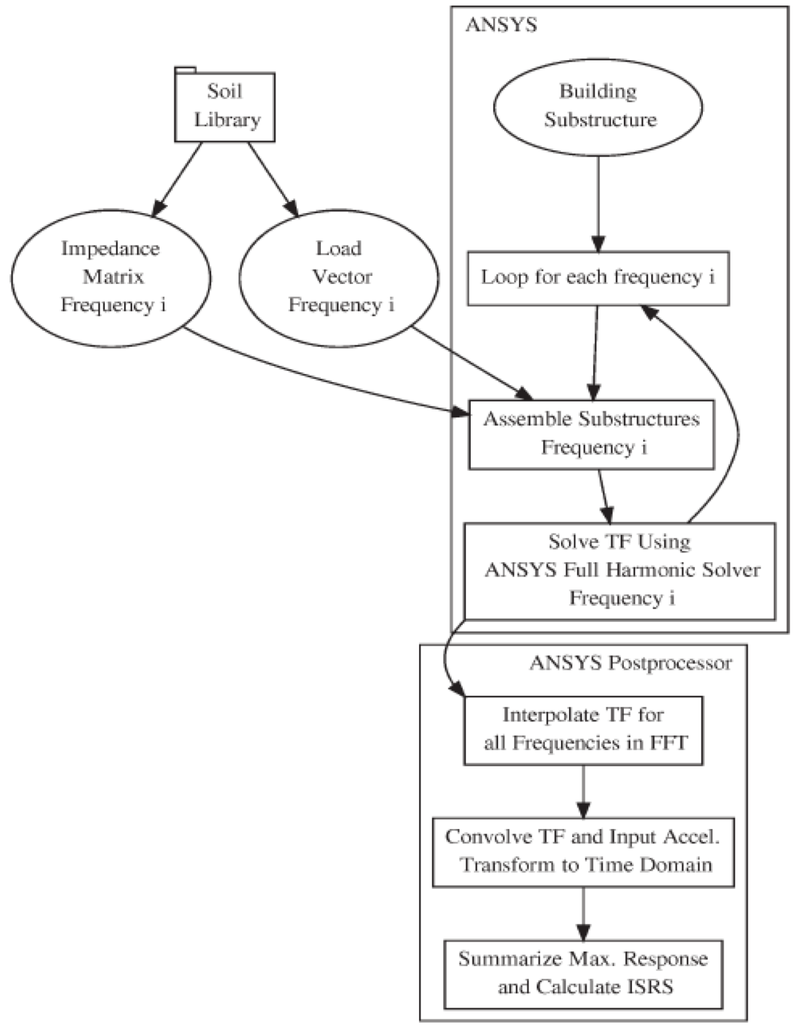




Soil Library Methodology

Combine soil and structural matrices and solve using ANSYS full harmonic solver

Interpolation of transfer function during post-processing by ANSYS uses same method as SASSI



ANSYS frequency domain solution

Topical Report Demonstration Problems

- Compared ANSYS and SASSI results
  - 1. PWR on surface of halfspace
  - 2. Embedded Building w/o fluid
  - 3. Embedded Building with fluid
  - 4. Representative Reactor Building with Soil-Structure-Fluid Interaction
- Conclusions
  - Excellent results comparisons
    - Transfer functions
    - Acceleration time histories and response spectra
    - Structural member design forces
    - Acoustic pressure time histories
  - ANSYS + Soil Library solution is functionally equivalent to a SASSI solution

Topical Report Review

- NRC Request for Additional Information (RAI) 9676 requested the inclusion of additional demonstration problems representative of more complex SMR structures
  - RAI 9676 response provided June 17, 2019
  - Topical Report Revision 1 submitted November 19, 2019 incorporated RAI 9676 responses (ML19168A249)
- Subsequent NRC audit requested supplemental discussion of software Verification and Validation process
  - Topical Report Revision 2 submitted September 2, 2020 augmented the V&V discussion

Summary

- Current methodology provides an accurate and conservative evaluation of seismic loads/demand
- Proposed methodology utilizes a one step analysis that is functionally equivalent and computationally more efficient
- NRC review and approval documented by safety evaluation

Acronyms

ANSYS – Analysis Simulation software

COL – Combined License

DCA – Design Certification Application

PWR – Pressurized Water Reactor

RXM – Reactor Module

SASSI – Analysis Software for Soil-Structure Interaction finite element analysis

SDA – Standard Design Application

SMR – Small Modular Reactor

SSFI – Soil Structure Fluid Interaction

SSI – Soil Structure Interaction

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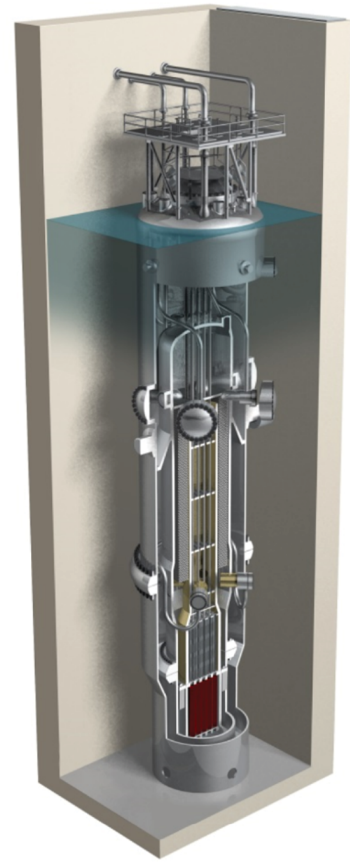

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United States Nuclear Regulatory Commission

Protecting People and the Environment

Staff Presentation to the ACRS Sub-Committee

NuScale Topical Report
Improvements in Frequency Domain
Soil-Structure-Fluid Interaction Analysis
(TR-0118-58005)

SEPTEMBER 22, 2020

Staff

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Agenda

- Introduction
- Regulatory Basis
- Background
- Proposed Methodology
- Staff Evaluation
- Limitations and Conditions
- Conclusions

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

Introduction

- This Topical Report (TR) describes an improved method for frequency-domain analysis of Nuclear Power Plant (NPP) structures with coupled soil, structure, and fluid interacting behaviors.
- The method provides an enhanced tool for an NPP licensee or applicant to calculate seismic demands for the design of structures, systems, and components (SSCs).

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Regulatory Basis

Regulations

- 10 CFR Part 50, Appendix A, GDC 2: SSCs important to safety must be designed to withstand the effects of natural phenomena such as earthquakes.
- 10 CFR Part 50, Appendix S: Safety functions of SSCs subject to earthquake ground motion must be assured through design, testing, or qualification methods and the evaluation must take into account soil-structure interaction effects.

Guidance

- NUREG-0800, SRP Section 3.7.2, Seismic System Analysis

Background

- Earthquake-induced seismic loads are a major contributor to the design loads for NPP SSCs.
- Effects of soil-structure interaction are considered in establishing seismic loads for an NPP built on a soil site.
- New fluid-filled NPP designs (small-modular reactors, advanced reactors) warrant consideration of the effects of soil-structure-fluid interaction in establishing seismic loads.
- No analytical tool is available for systematically integrating the effects of soil-structure-fluid interaction in developing seismic loads for NPP SSCs.

Background

- Soil-structure interaction (SSI) analysis is typically performed using the SASSI* computer code. However, SASSI does not have the capability to effectively handle fluid-structure interaction (FSI).
- FSI analysis can be performed using a finite element analysis code, such as ANSYS**. However, ANSYS does not have the capability to effectively handle SSI.
- The TR proposes a methodology that integrates the capabilities of SASSI and ANSYS to handle soil-structure-fluid interaction during the earthquake.

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* **SASSI** ("A System for Analysis of Soil-Structure Interaction") is an analysis code originally developed at University of California, Berkeley in 1981.

** **ANSYS** is a general-purpose finite element analysis code.

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Proposed Methodology

- The elements of the proposed methodology consist of substructures representing interacting entities involved in the analysis – the soil substructure, building substructure, and fluid substructure.
- These substructures collectively represent a coupled soil-structure-fluid interactive system that is analyzed for a prescribed ground motion.
- Different soil substructures, representing different site soil conditions, can be created and stored, and an integrated analysis can be performed for each different soil substructure without impacting the other substructures.

Assumptions

The proposed methodology is based on the following assumptions:

- Material properties are linear elastic during the analysis;
- Behavior of boundary conditions and constraints is linear; and
- Seismic load is represented by vertically propagating shear and compression waves.

Staff Review: Assumptions

1. NRC staff reviewed and determined that applicant's assumptions on the linearity of material properties, linearity on boundary conditions and constraints, and seismic load represented by vertically propagating seismic waves are consistent with the established state-of-the-practice in SSI analysis of nuclear structures and with provisions of American Society of Civil Engineers (ASCE), Standard 4-16.
2. Staff, however, notes that site-specific considerations may invalidate the applicability of any one of these assumptions for a particular analysis. Accordingly, the staff finds these assumptions to be acceptable, provided that each of these assumptions is a **condition and limitation** on the applicability of the TR for any particular analysis, as delineated in "Limitations and Conditions" Section of the staff's Safety Evaluation.

Computer Codes Used

Two computer codes are used in the development and evaluation of the proposed methodology by the applicant:

- ANSYS, Version 18.1
- SDE-SASSI, Version 2.1

Staff Review: Computer Codes

- **ANSYS V.18.1**

NRC staff recognizes that ANSYS is a commercially available general-purpose finite element code that has been widely accepted by the engineering community and the NRC staff's experience is that the results obtained from ANSYS have been acceptable. Therefore, ANSYS used in the TR can be accepted without further evaluation.

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Staff Review: Computer Codes

- **SDE-SASSI V.2.1**

NRC staff reviewed the Acceptance Testing Report for SDE-SASSI code used in the development and evaluation of the proposed methodology and determined that the use of the code is acceptable because:

1. The selection of acceptance test problems is adequate as the range of input parameters considered in these test problems covers the range of input parameters expected in the application of the analysis methodology proposed in the TR;
2. The methods of modeling and analysis employed for the test problems conform to the guidelines in NUREG-0800, SRP Section 3.7.2; and
3. The solutions from SDE-SASSI are comparable with the benchmark solutions from the established theory and numerical methods.

Solution Workflow

The following summarizes the solution workflow for an integrated analysis of seismic soil-structure-fluid interaction proposed in the TR:

Step 1: In SASSI, model Soil Substructure and derive parameters necessary to capture the seismic SSI effects. These parameters include soil impedances and seismic load vectors and are stored in the "Soil Library", which can be exported into ANSYS.

Step 2: In ANSYS, model Building Substructure and Fluid Substructure using appropriate structural and acoustic elements that capture the FSI effects.

Step 3: In ANSYS, integrate the SSI effects (from imported Soil Library) and FSI effects (using ANSYS finite elements), and then solve the resulting equations of motion to determine the seismic loads for SSCs, fully accounting for the soil-structure-fluid interaction effects.

Staff Review: Solution Workflow

NRC staff reviewed the information on the applicant's solution workflow for frequency-domain soil-structure-fluid interaction analysis and finds them acceptable because:

1. SSI parameters contained in the Soil Library (soil impedance matrices and seismic load vectors) are derived within the framework of the established SASSI methodology (e.g., SASSI 1981);
2. Building and Fluid Substructures and FSI effects are analytically modeled using the established ANSYS structural and acoustic elements;
3. Modeling and analytical procedures used in the proposed workflow conform to the guidelines in NUREG-0800, SRP Section 3.7.2; and
4. Adequacy of the solution workflow is further validated through the example problems presented in the TR .

Enhanced Solution Features

TR describes enhancements to the established SASSI methodology, which were applied to the proposed methodology:

- For efficiency, the Soil Library (containing soil impedance matrices and seismic load vectors) can be compressed in size through the condensation of internal soil degrees of freedom.
- SDE-SASSI has the ability to solve an SSI problem using an ANSYS substructure containing the fluid-structure interaction.
- SDE-SASSI has the ability to solve equations with non-symmetric mass and stiffness matrices associated with fluid-structure interaction problems.

Staff Review: Enhanced Solution Features

NRC staff reviewed the information on the applicant's enhanced solution features developed and applied to the proposed methodology and find them acceptable because:

1. Mathematical operations involved in developing the enhanced features conform to the established mathematical principles;
2. Equations and parameters used in the enhanced features are consistent with the established principles of dynamics of structures and fluids; and
3. The validity of the enhanced features is demonstrated through example problems provided in the TR.

Example Problems

TR includes four Example Problems to illustrate and validate the use of the proposed methodology:

- Problem 1: a surface-founded containment building with soil-structure interaction
- Problem 2: a partially-embedded box-shaped building with soil-structure interaction
- Problem 3: a partially-embedded box-shaped building with soil-structure-fluid interaction
- Problem 4 (added in response to RAI 9676): a representative SMR building with a pool accounting for soil-structure-fluid interaction

Staff Review: Example Problems

NRC staff reviewed the Example Problems and the results provided in the TR and found the following:

1. Staff observed that results from Example Problems support the adequacy of the proposed Soil Library approach to solving the soil-structure-fluid interaction problem.
2. Staff identified good agreement between results from ANSYS and SDE-SASSI, which support the validity of the proposed workflow and enhanced solution features.
3. Staff concludes that the examples problems in the TR provide an evidence that the proposed frequency-domain soil-structure-fluid interaction analysis methodology is adequate.

Limitations and Conditions

NRC staff's approval of this TR is limited to the proposed analysis methodology applied to problems that satisfy the assumptions set forth by the applicant in Section 3 of this TR, specifically, that: (1) all material properties are linear-elastic during the analysis, (2) the behavior of boundary conditions and constraints is linear, and (3) the seismic load is represented by vertically propagating shear and compression waves. A licensee or applicant who applies the analysis methodology approved in Staff's SE to a site-specific problem must consider the applicability of these limitations to the site-specific conditions, and the NRC staff will verify that each of these conditions has been satisfied in its review of a site-specific application.

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Conclusions

NRC staff has completed its review of this TR and concludes that, subject to the limitations and conditions as specified in Section 6.0 of Staff's SE, the frequency-domain analysis methodology described in this TR is acceptable to perform seismic soil-structure-fluid interaction analysis to establish seismic demands for the seismic qualification of structures, systems, and components, in accordance with the guidance in NUREG-0800, SRP Section 3.7.2, and thus in compliance with the applicable regulatory requirements delineated in Section 2.0 of Staff's SE.

Abbreviations

ANSYS	An Analysis Software
ASCE	American Society of Civil Engineers
FSI	Fluid-Structure Interaction
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
RAI	Request for Additional Information
SASSI	A System for Analysis of Soil-Structure Interaction
SDE	Structural Dynamics Engineering
SE	Safety Evaluation
SMR	Small Modular Reactor
SRP	Standard Review Plan
SSC	Structure, System, and Component
SSI	Soil-Structure Interaction
SSFI	Soil-Structure-Fluid Interaction
TR	Topical Report

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Questions?

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(Back-Up)

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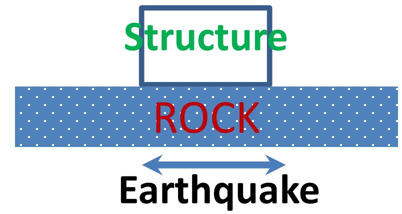
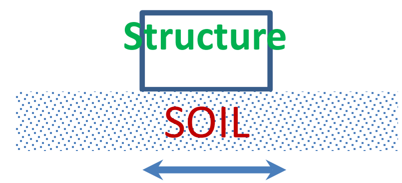
Illustrations of Soil, Structure, Fluid in Interaction

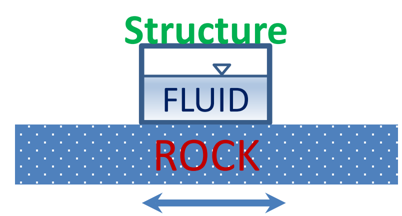
- Case 1: A structure on rock. A standard structural analysis to be performed



- Case 2: A structure on soil. Soil-Structure Interaction to be considered (e.g., SASSI* can be used for analysis)



- Case 3: A fluid-filled structure on rock. Fluid-Structure Interaction to be considered (e.g., ANSYS** can be used for analysis)



- Case 4: A fluid-filled structure on soil. Soil-Structure-Fluid Interaction to be considered (focus of this TR)