

TRANSFERRING SSI INTO TIME DOMAIN

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ABSTRACT

In nuclear engineering, ACS-SASSI is a time and cost-efficient tool for seismic calculations in the complex frequency domain. However, recent discussions and developments focus on the alternative time domain-based Domain Reduction Method (DRM). The DRM especially introduces the possibility to incorporate nonlinearities, yet albeit by an increase in computation time. Additionally, in a first step the domain reduction method has to be calibrated with a preliminary SASSI calculation.

In response to the evolving landscape, ACS-SASSI has introduced Option A-AA [Ghiocel, D. M., Saremi M. (2017)], a feature list that combines the frequency domain efficiency of ACS-SASSI with the time domain variability of ANSYS. Basically, it enables users to extract seismic calculation results and apply them as boundary conditions in ANSYS.

This paper investigates a practical implementation of this approach, wherein time history displacements extracted from an ACS-SASSI seismic calculation are employed as boundary conditions in a Finite Element Method (FEM) Solver, here ANSYS. This implementation is motivated by the desire to combine the established numerical efficiency of ACS-SASSI Soil-Structure Interaction (SSI) calculations, achieved through mode superposition in the frequency domain, with the capabilities of ANSYS in performing nonlinear calculations in the time domain. The approach retains the original size of the model and avoids the introduction of additional elements in the soil area.

A simple model is used in a first step to verify the basic idea and the implementation. The influence of the damping parameter is investigated. The gathered knowledge is then tested in a more sophisticated model. In line with the need for absolute displacements for the calculations a baseline correction is introduced and validated by the approach ACS-SASSI uses to obtain absolute displacements.

Results from the presented case study demonstrate the reproducibility of ACS-SASSI results in an ANSYS environment, validating both ACS-SASSI and the utilized baseline correction from [J. Yang, J.B. Li, G. Lin (2005)].

INTRODUCTION

In 2017, [Ghiocel, D. M., Saremi M. (2017)] presented ACS-SASSI's ability to extract and apply Soil-Structure Interaction (SSI) results in ANSYS. Having implemented binary files for post-processing and ANSYS-cdb file export/import compatibility, this functionality simplifies the displacement extraction in ACS-SASSI and boundary condition application in ANSYS. These practical features allow an implementation of the extraction of displacements and their use as boundary conditions.

In detail ACS-SASSI features the following options to migrate results from ACS-SASSI to ANSYS:

- 1) Option AA: One step analysis. ACS-SASSI is used for the seismic computation,
- 2) Option A: Two step analysis. In a first step ACS-SASSI computes the SSI and in the second step the results are used in ANSYS as boundary conditions.

Option A then features the following:

Option i	equivalent static
Option A	relative displacement at every degree of freedom (DOF)
Option B	nodal seismic forces + relative displacement at foundation soil interface
Option ii	equivalent dynamic
Option A	SSI absolute displacements at the foundation soil interface
Option B	SSI structure accelerations+SSI relative displacements at foundation soil interface

In the authors view the most straightforward method is the application of absolute displacements at the soil foundation interface (option ii–A). This “direct load/displacement transfer” not only allows to reproduce the displacements of the building, but also allows to verify base line correction methods and to verify assumptions being made in a seismic analysis, particular expecting only a linear response of the building. This approach however can easily be changed to option i–A.

ACS-SASSI refers to this integration capability as a cascaded approach, meaning that the transmission of the boundary conditions is only valid, while the introduced possible finetuning of the FEM-Modell in the time domain does not have an effect backwards on the SSI-calculation. This is, of course, very restrictive and thus a disadvantage of this option, especially in comparison to the DRM.

The advantages of these options are a runtime efficient calculation of a seismic event in conjunction with an efficient stress calculation, which is in the current ACS-SASSI environment in the authors view sometimes cumbersome. In addition, the calculation of seismic events sometimes requires at least nine different calculations or even up to thirty calculations for probabilistic simulations. Time efficiency therefore remains an important factor in these calculations.

In line with the implementation of this approach a base line correction is introduced, presented in [J. Yang, J.B. Li, G. Lin (2005)] to correct the accelerations and to filter drifting effects, leading to nonzero deformations at the end of the seismic event.

BRIEF DESCRIPTION OF THE IMPLEMENTATION

As a basis, the accelerations and relative displacements are extracted from the binary files of the model using Python scripting. The absolute displacements are then calculated using two different approaches, which are presented below. The results are converted into tables, that can be read by ANSYS and applied at the xyz-coordinates of the interaction nodes in the ANSYS model as boundary conditions.

Approach 1: Integration with Baseline correction

One approach to get the absolute displacements is to apply the baseline correction of the accelerations and then integrating twice. Here the baseline correction from [J. Yang, J.B. Li, G. Lin (2005)] is used. Its basic idea is the assumption of zero initial conditions. This goes hand in hand with the assumptions used here for the excitation of the building, since a two-time integration of the excitation shows zero displacements, velocities and accelerations at the ground of the building initially and after the seismic event. The applied baseline correction assumes, that the displacement of the baseline takes the following polynomial form

$$u = a_1 t^4 + a_2 t^3 + a_3 t^2 + a_4 t. \quad (\text{Eq. 1})$$

By deviating the displacement from Eq. 1, the velocity and acceleration can be calculated. With a_1 to a_4 being the constants to determine. In [J. Yang, J.B. Li, G. Lin (2005)] constant a_4 is derived by the physical sane assumption of zero initial displacement. By then minimizing the mean square acceleration for every node i in N via

$$\min \left\{ \sum_{i=1}^N |(\ddot{u}_i - \ddot{u}_i)^2| \right\}, \quad (\text{Eq. 2})$$

with \ddot{u} being the acceleration calculated by ACS SASSI and \ddot{u} being the second derivative of Equation 1. The result of Equation 2 is then the baseline corrected acceleration.

An additional part in [J. Yang, J.B. Li, G. Lin (2005)] presents a high-pass filter in the frequency domain. This is not applied here, since on one hand it introduces additional parameters to be varied and therefore adds some complexity and on the other hand the correction already introduced feasible results.

As a drawback it should be mentioned that a baseline correction is in general not flawless and is for example not accepted by the USNRC.

Approach 2: Freefield displacements + relative displacements

The second approach to calculate the absolute displacements is used by ACS-SASSI. It is achieved by integrating the freefield excitation accelerations twice (they are free from spurious drifting effects) and adding them to the relative displacements calculated in ACS SASSI, which uses an analytical approach rather than baseline correction.

In Figure 1 the basic idea of the procedure and its test is presented. The red dot represents the time history displacement extracted from ACS-SASSI that is applied to the right side in ANSYS. The green dot represents a characteristic node, where the displacement time history from ACS SASSI and ANSYS is compared.

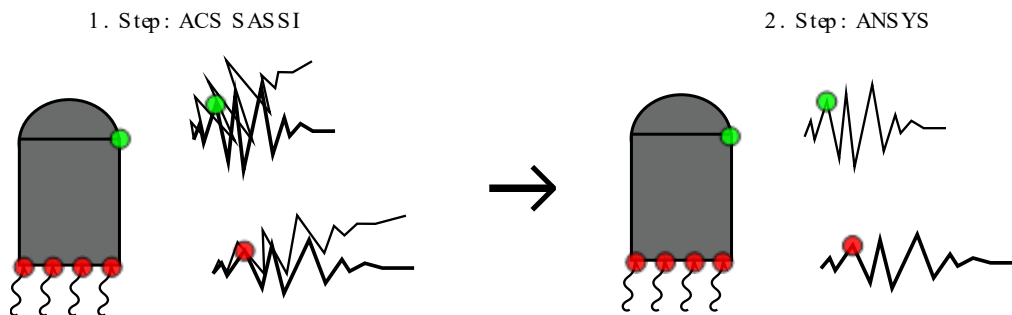


Figure 1 The basic procedure. The results from the first step “ACS-SASSI calculation” are used in the second step “ANSYS calculation” as boundary conditions.

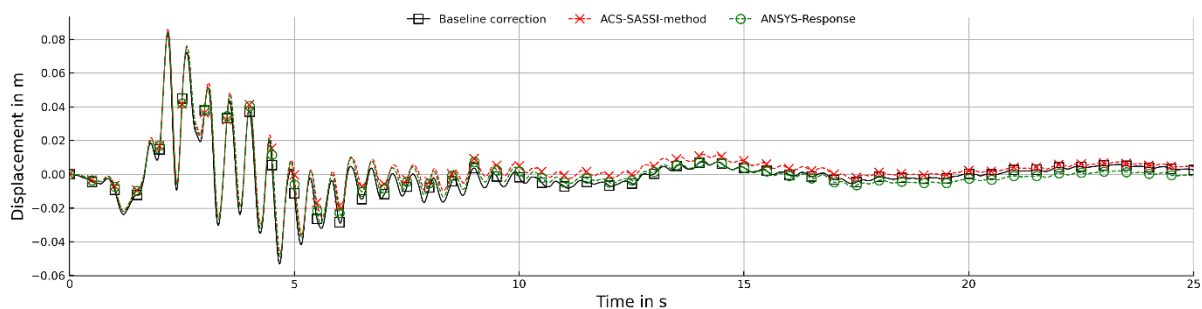
Remark: The very basic idea of applying a time history curve to only a part of a damped model (in ACS-Sassi the whole model is included, in Ansys only the building) was tested previously on a simple beam model in the time domain in Ansys. A perfect replica of the results can be generated.

COMMENTS ON THE BASELINE CORRECTION

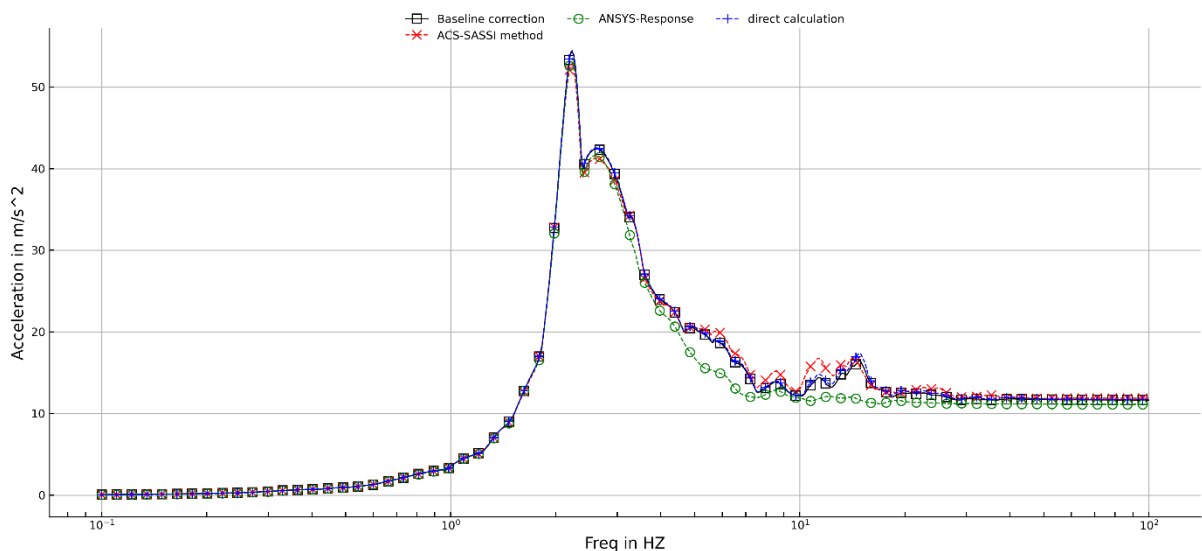
The approach of applying baseline corrected displacements at the interaction nodes as boundary conditions leads to a welcoming verification of the baseline correction. By comparing the displacement time history response at higher nodes in the ANSYS model to the baseline corrected displacement time history response at those nodes from ACS SASSI, a good correlation indicates a well working baseline correction. Since the movements at the higher nodes are a direct deviation of the applied boundary conditions at the ground, this approach shows, that the baseline correction keeps this connection between the movements in the ground and in the building.

Additionally, by comparing the response spectra of the initial acceleration with the baseline corrected acceleration and again finding at best no difference, it can be made sure that the baseline correction produces reasonable results.

In anticipation of the later sections, some results are already presented here to justify the use of the baseline correction method. In Figure 2 the absolute time history displacement of both methods is shown for the later introduced more complex model. Figure 2 a) thereby shows the ACS-SASSI absolute method (adding the relative displacement to the two times integrated excitation acceleration) and the two times integrated baseline corrected acceleration. They show a similar curve, yet there is a slight shift between the centerline. In Figure 2 b) the response spectrum of those curves (2 times deviated) is compared to the directly calculated acceleration. It can be seen that there is a slight deviation to the direct calculation, which is in an acceptable range.



a) The results of the calculated absolute displacements by both approaches (Node 8601).



b) The comparison between the response spectrum by both method plus the response spectrum directly calculated from the acceleration (Node 8601).

Figure 2 Displacement history calculated by the presented methods and the response spectrum compared to each other (Node 8601).

ILLUSTRATIVE SIMPLE MODEL

First a simple model is presented, which consists of a foundation with solid elements and the building cylinder wall with shell elements. The material for all elements is concrete with $E = 35\,000\text{ MPa}$ and $\nu = 0.3$. The model is presented in Figure 3. The interaction nodes are only at the bottom row of the blue area (SOLID45-elements), while the characteristic structural node is in the top of the red region (SHELL63-Elements). For convenience, although to be treated carefully, in a first step damping is

neglected (see Figure 4). Then, in the second step, the Rayleigh-Damping is adjusted with the first Eigenmode 4 Hz of the simple model (see Figure 5).

For the simple model depicted in Figure 3 a) the results from the undamped calculation at the characteristic node are presented in Figure 4. The calculated displacements and thus the response spectra of the acceleration results are in exact correlation.

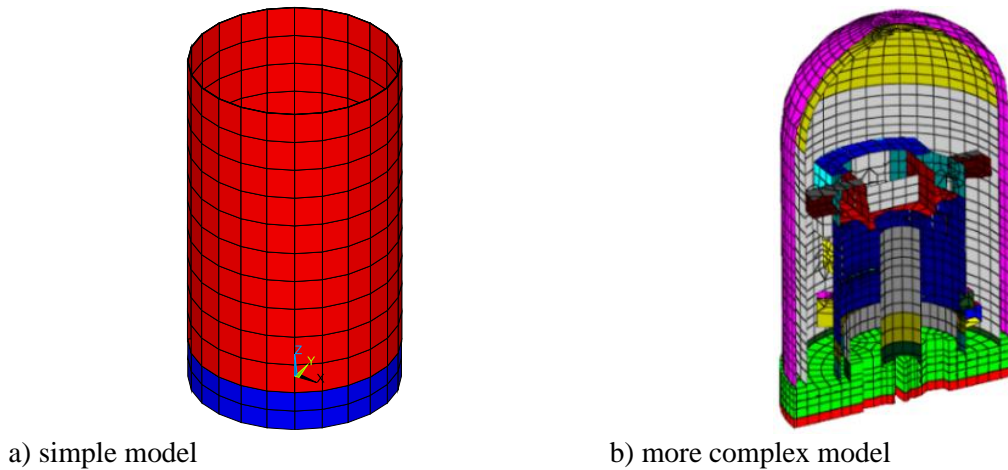
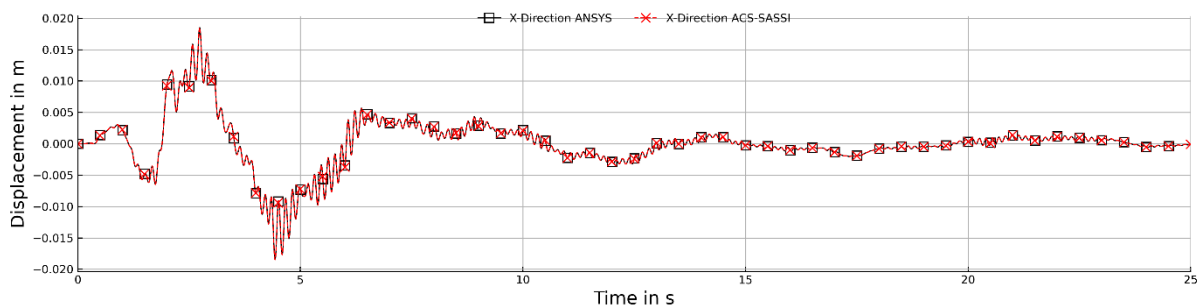
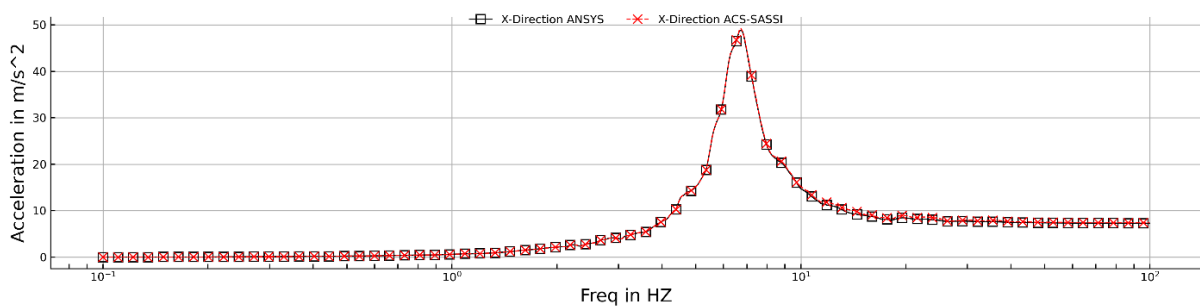


Figure 3 The models.



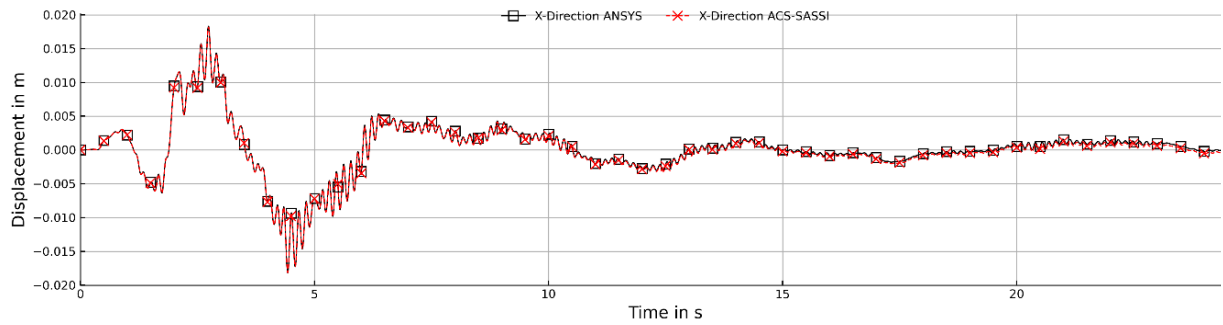
a) Displacement time history at Node 374 (characteristic node).



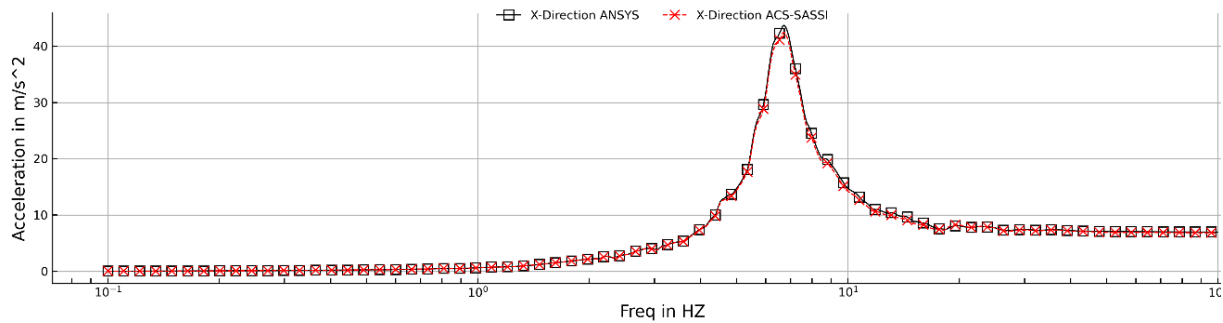
b) Response spectrum (5 %) at Node 374 (characteristic node).

Figure 4 Results from ACS-SASSI and ANSYS in an undamped simple model.

The introduction of damping (7 %) in the second step causes the results to decrease visibly in Figure 5 a) and b). The results between ANSYS and ACS-SASSI are still in good agreement. A slight deviation at about 7 Hz can be seen in the response spectra in Figure 5 b). Considering this, the deviation could also be found in the small waves around 5 s in Figure 5 a). It should be noted that the Rayleigh damping has to be adjusted carefully for the ANSYS calculation and because of its frequency dependent nature, it always will differ from the ACS-SASSI calculation. This deviation will increase with the complexity of the model or more exact with the number of dominant eigenmodes.



a) Time history displacement at Node 374 (characteristic node).



b) Response spectrum (5 % damping) at Node 374 (characteristic node).

Figure 5 Results from ACS-SASSI and ANSYS in a 7%-damped simple model.

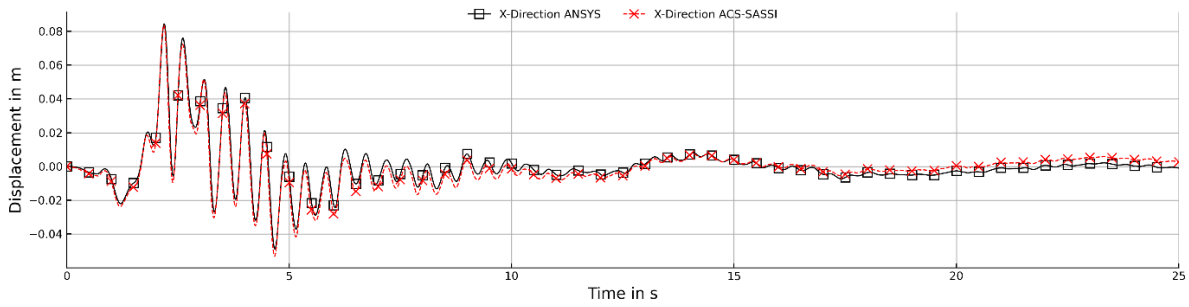
Summarized it could be shown that the results can be recreated for the simple model and that the baseline correction is a feasible option in this case. So, the transfer from ACS-SASSI to ANSYS is validated for the simple model.

ILLUSTRATIVE COMPLEX MODEL

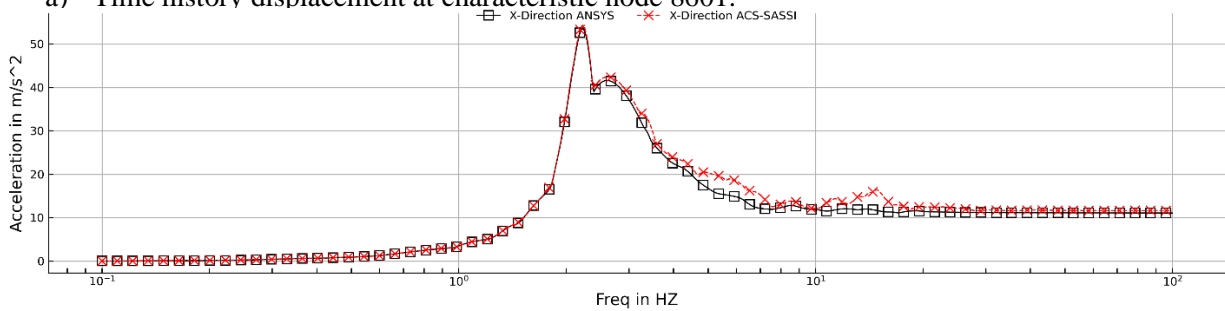
A more complex embedded (reactor building) model is presented in Figure 2 b). Here the material for the elements is again concrete with $E = 35\,000\text{ MPa}$ and $\nu = 0.3$. Additionally, there are some beam elements with steel as material, representing fuel racks, polar cranes and other equipment, which is of minor interest for the overall results. The red elements at the bottom in Figure 2b show the embedding of the model.

Initially, the damping is chosen to be very low (0.5 %), so the influence of a frequency dependent Rayleigh-damping on the results is minimized. The time history displacements and the response spectra at the characteristic node are presented in Figure 6 for ACS-SASSI and ANSYS results. As stated previously a low damped system shows a reasonable agreement. The response spectra in Figure 6 b) have some deviations starting from 2.4 Hz up to about 20 Hz. This 2.4 Hz corresponds to the visible oscillation in the time history plot in Figure 6 a), which can be seen around 5 s. Additionally, a very low frequency movement (below 0.03 Hz) can be seen, which results in a deviation of the centerline of the time history plot. It may be a result of the low frequency overdamping effect of the Rayleigh-damping. The unused high-pass filter of [J. Yang, J.B. Li, G. Lin (2005)] can also explain the visible deviations. However, this small offset has no influence on the response spectra.

Since the displacement time history shows a difference between the baseline corrected time history displacement from ACS-SASSI and the resulting time history displacement from ANSYS, both approaches to calculate the absolute displacement are compared to each other in section “COMMENTS ON THE BASELINE CORRECTION”.



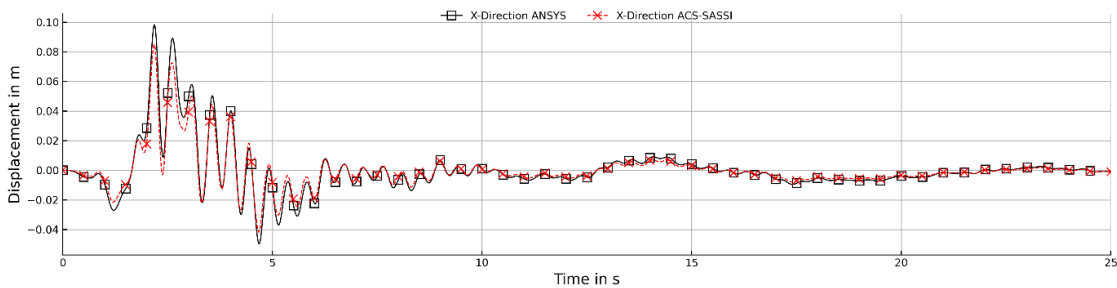
a) Time history displacement at characteristic node 8601.



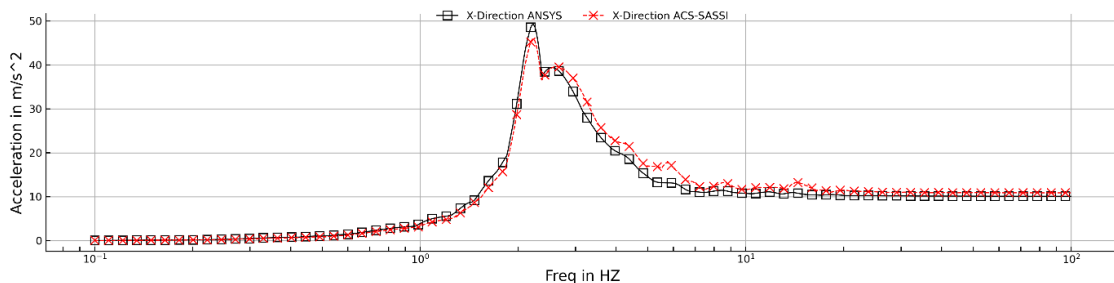
b) Response spectrum at characteristic node 8601.

Figure 6 Results from ACS-SASSI and ANSYS in an undamped complex model (Node 8601).

In the next step the damping of the complex model is set to 5%. By an increase of the damping the basic movement of the building is still depicted in the ANSYS calculation. In Figure 7 a) the displacement time history is shown for the ACS-SASSI and ANSYS results. There is still a reasonable agreement between the two curves, but a deviation is already visible in the range of interest between 2 s and 7 s, while there is a very good matching from 10 s until the end.



a) Time history displacement at characteristic node 8601 (system wide damping of 5%).



b) Response spectrum at characteristic node 8601 (system wide damping of 5%).

Figure 7 Results from ACS-SASSI and ANSYS in a damped (5 %) more complex model.

The response spectra are compared in Figure 7 b). The observed deviation from ACS-SASSI and ANSYS results can be found in the frequency range from about 1 Hz to 10 Hz. However, an additional correction

of the damping is not necessary, since the deviation is in an acceptable range. This is particularly the case because the node of interest (node 8601) is located at the top of the building. So the observed deviations are much smaller in the lower part of the building.

INFLUENCE OF NONLINEARITIES

The main disadvantage of this model is the two-step cascaded approach without backward effects between the two steps. Although nonlinear effects can be implemented, it is not possible to remap their influence on the soil – if there is one. Here the DRM-method can play a decisive role by investigating those effects resulting from concrete cracking, foundation sliding, uplift effects, and nonlinear structure behavior due to larger deformations.

In spite of that, the present method could be used to evaluate whether a nonlinearity results in interaction effects or not. This can be done by adding some soil elements into the model with i.e. contact between soil and foundation. A parameter study with increasing the amount of soil elements around the foundation, could show if the problem converges and interaction effects are small. If not, one will finally end up with a DRM model.

CONCLUSION AND OUTLOOK

The capabilities of ACS-SASSI allow the simple extraction of results of seismic SSI calculations. This is in particular to use ANSYS models in ACS-SASSI and the efficient use of binary files for an efficient postprocessing. In the presented implementation a seismic calculation is carried out with ACS-SASSI. The accelerations at the interaction nodes are extracted, transformed and applied as displacement boundary conditions in ANSYS. To do so, a simple baseline correction from [J. Yang, J.B. Li, G. Lin (2005)] is used and briefly introduced and verified.

The movements of the building in both program environments are compared and it can be shown that ANSYS recreates similar results in the first step for a simple model and in the second step for the complex model. The different damping methods proved to be particularly influential. While ACS-SASSI works in the complex frequency domain with constant damping, ANSYS works in the time domain with frequency dependent Rayleigh damping. For that reason, it is necessary to adjust the Rayleigh damping coefficients which requires experience and testing. The deviation of the results between ACS-SASSI and ANSYS is in an acceptable range. Further improvement can be made by adjusting the damping with the help of a parameter study.

The domain reduction method has its valuable advantage against the here presented option, since, once established, can be used to investigate nonlinear behavior. For the here presented models only well argued conservative results can be achieved. However, with relative small effort the tendency of nonlinearities can be investigated and this can already be of some benefit.

An interesting outlook from the authors point of view is, to further integrate soil elements in the model and thus increase the model size, which would make nonlinearities in the building become less influential. This then could be a feasible option to include nonlinearities even with this method and the domain reduction method would be less advantageous.

REFERENCES

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- J. Yang, J.B. Li, G. Lin (2005), *A simple approach to integration of acceleration data for dynamic soil–structure interaction analysis*, Soil Dynamics and Earthquake Engineering, Volume 26, Issue 8, 2006, Pages 725-734, ISSN 0267-7261