*Transactions*, **SMiRT-26**
**Berlin/Potsdam, Germany, July 10-15, 2022**
**Division III**

# EXPERIENCE IN CALCULATING THE SOIL-STRUCTURE INTERACTION DYNAMIC EFFECTS USING LS-DYNA

**Alexander Kultsep [1], Nataliia Igrashkina [2]**

[1] PhD, Principal Engineer, CKTI-Vibroseism, St. Petersburg, Russia (AKultsep@cvs.spb.su)
[2] PhD Student, University of Nevada, Reno, Reno, NV, USA (nigrashk@buffalo.edu)

## ABSTRACT

Verification calculations of the interaction between the structure and the soil under seismic excitation have been carried out using the effective seismic input method implemented in LS-DYNA software, Hallquist (2017). Two test examples performed using the ASC SASSI software, Ghiocel (2016), were used as control solutions.

Verification of the effective seismic input method implemented in the LS-DYNA software resulted in good agreement with results obtained using the control solutions. In the case of surface placed structure, the maximum error in response spectra calculation is less than 10 %. For the embedded structure, less accurate but more conservative results were obtained, with the maximum error of 24.5 % in the calculation of ZPA.

## INTRODUCTION

Soil-structure interaction (SSI) calculation method implemented in the ASC SASSI software is the state of the art in dynamic calculations of nuclear buildings. A method implemented in the LS-DYNA software has some advantages but is not as widely validated as the ACS SASSI method. The aim of the present work was to compare both the methods using simple and clear examples.

## CALCULATION METHOD

Calculations of the interaction of the structure with the soil under seismic excitation were performed using the effective seismic input method, implemented in the LS-DYNA software, see Basu (2009).

The analysis was performed in two steps. In the first step, a soil with an excavated volume for the construction of a structure is considered. The initial impact is given in the form of accelerograms that describe the movement of the original soil (without excavation) on the surface of the considered excavated volume, and then the forces that must be applied to the walls of the excavated volume to replace the missing soil are calculated. The calculated forces are written to a special file (gmbin).

In the second step, the model is supplemented with a model of the structure placed in the excavation. The structure model is connected to the walls of the excavation through a special interface (*INTERFACE_SSI). Next, an analysis is performed for the same excitation in the free field, for which the calculation of the first step was performed, and, taking into account the results of the first step, recorded in the gmbin file, the seismic response of the structure is determined.

For surface structures, a similar procedure can be applied, but performed in one step, since in this case there is no need to determine the interaction forces on the interface surface in the absence of a structure.

## TEST EXAMPLE 1

For the first test example, a rectangular monolithic structure (tower) with plan dimensions of 2x2 m and a height of 3 m, located on the surface of an elastic soil (half-space) was considered. This example is presented on the LS-DYNA web site, see LSTC (2017). In this example the same material parameters were used for soil and structure: E = 1000 N/m$^2$, μ = 0.25, ρ = 1 kg/m$^3$. The seismic excitation was specified on the ground surface as a three-component acceleration record from the El Centro earthquake.

Unfortunately, this example was not very useful as a verification test for the following reasons:

1) radiation damping in the soil for the lowest mode of oscillation of the considered structure is less than 1 %, which leads to a sharp peak of a transfer function and high sensitivity of the resulting response to the errors of the calculation scheme;

2) in addition to item 1, because the natural frequency of the oscillations is less than 1 Hz, and the accelerogram of the El Centro earthquake under consideration has a very low spectral density in the low frequency range, it was not possible to evaluate the accuracy of the solution at the main frequency of the building oscillations.

In this regard, the following changes were made in the problem under consideration: the density of the tower material was reduced to 0.1 kg/m$^3$ while maintaining the soil parameters, and the accelerogram was replaced by a synthetic one.

The seismic load was set as soil surface motion in the form of the mentioned synthetic accelerogram, the graph of which is shown in figure 1. The seismic excitation was applied separately in vertical and horizontal directions using the same record.

As a control solution, the problem was solved using the ACS SASSI software. Material damping in the soil and tower materials was not considered in order to exclude the difference in results due to different approaches to account for material damping in the ASC SASSI and LS-DYNA programs. Thus, the damping in the test under consideration was realized due to radiation damping in the soil only.

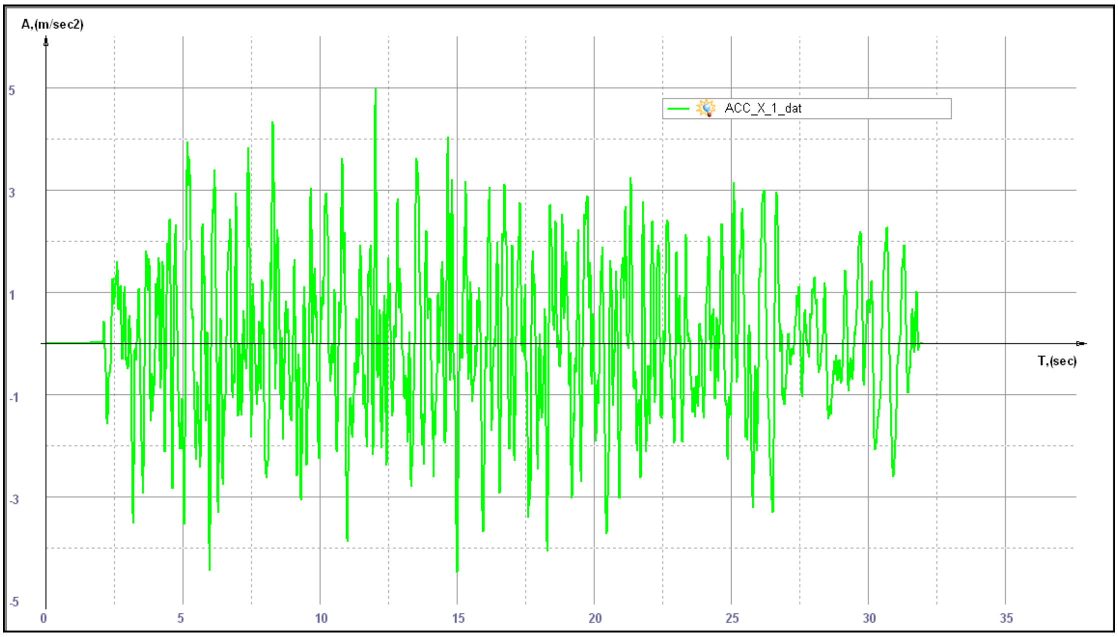


Figure 1. Synthetic accelerogram.

Figures 2 and 3 show the resulting transfer functions for the top and bottom of the tower under vertical and horizontal excitation. Figures 4 and 5 show the resulting response spectra for X excitation and figure 6 - for Z excitation, at tower base and top levels. Numerical results comparison for zero period acceleration (ZPA) and maximum spectral acceleration (MSA) calculated at tower base and top levels is presented in table 1. Results show good agreement between two calculation methods.

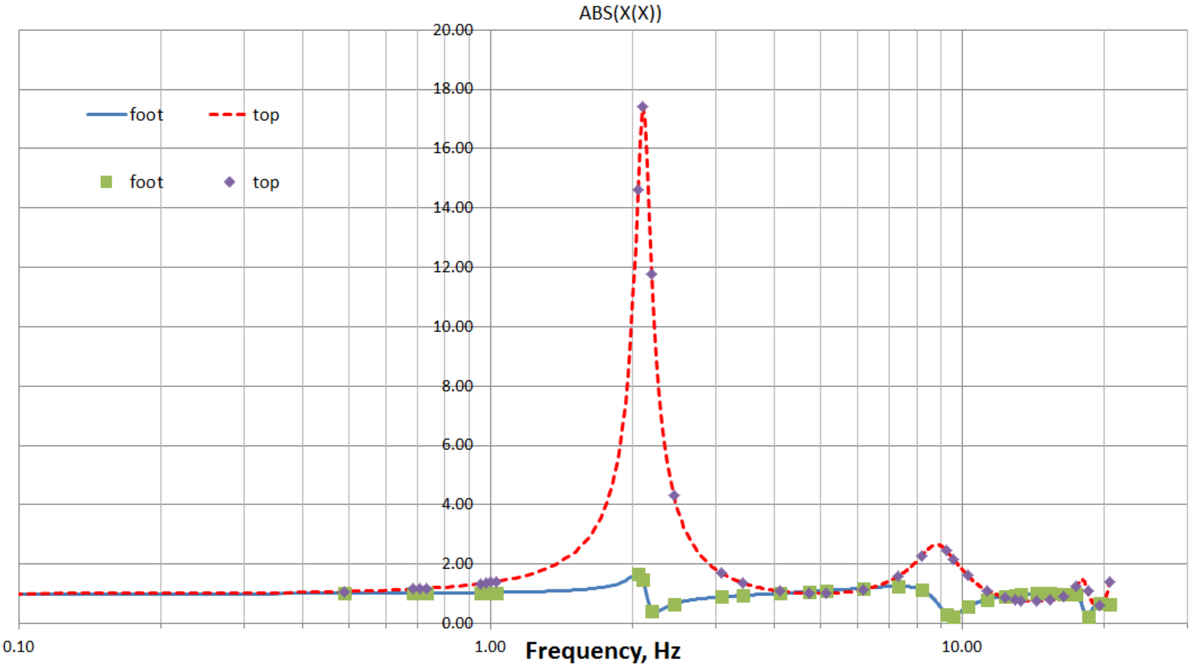


Figure 2. Test 1, Transfer function for X direction.

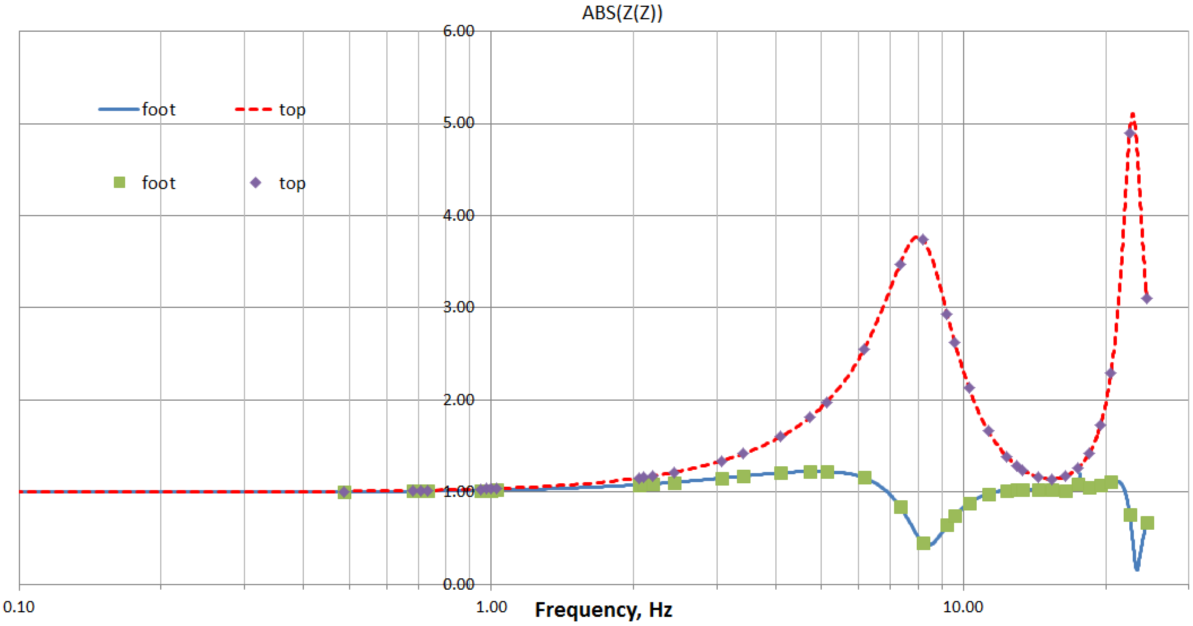


Figure 3. Test 1, Transfer function for Z direction.

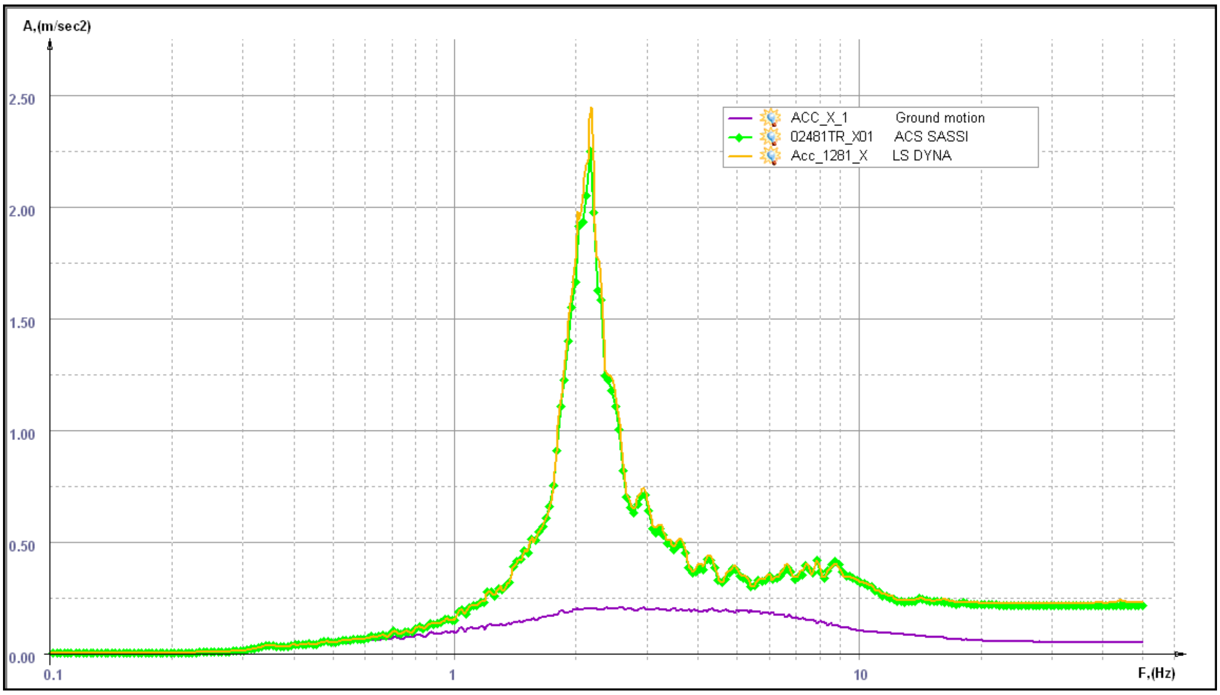


Figure 4. Test 1, Response spectra for X direction at tower top.

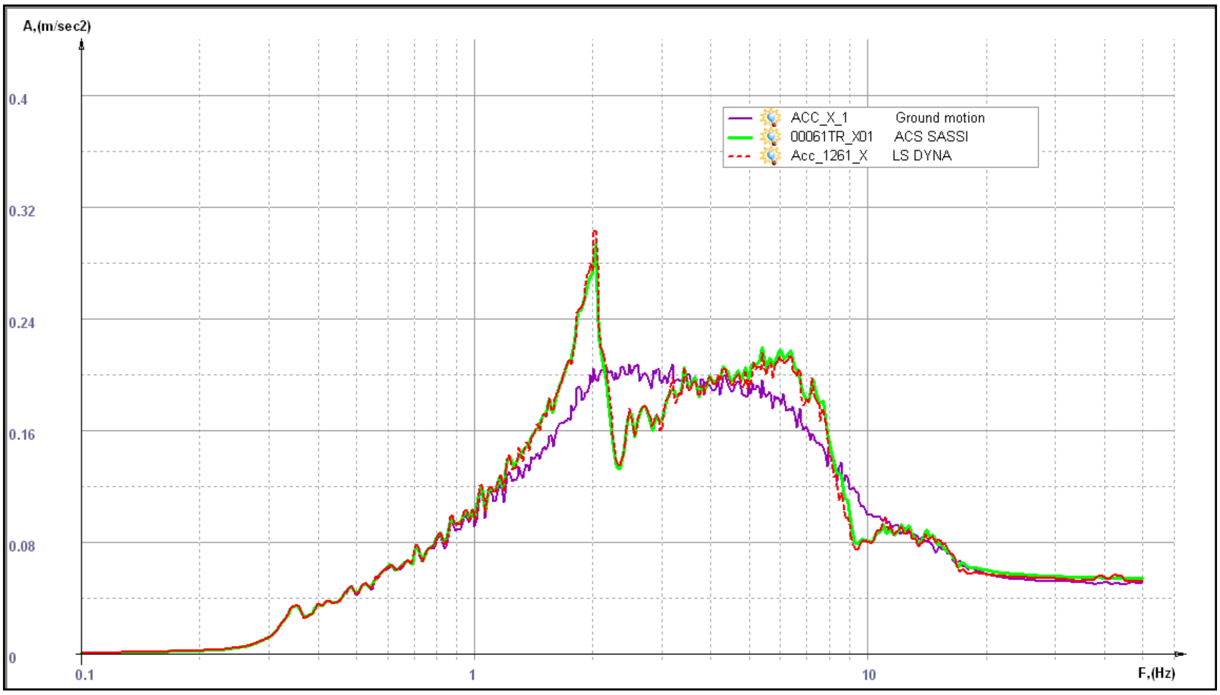


Figure 5. Test 1, Response spectra for X direction at tower base.

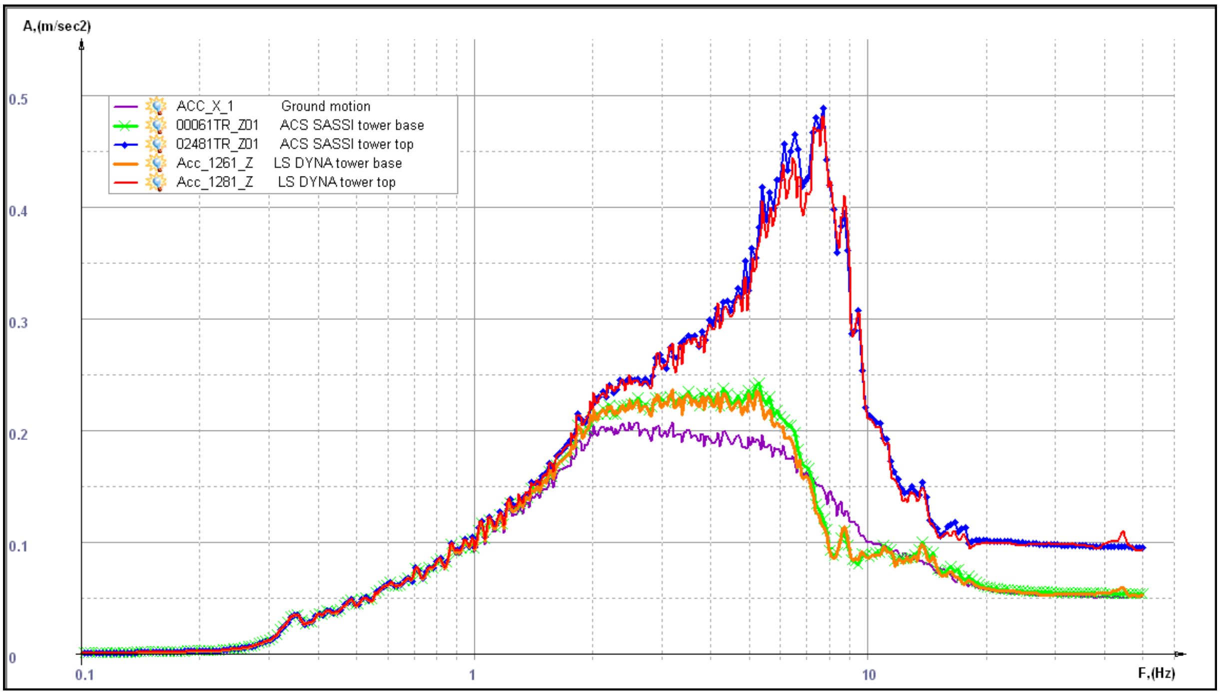


Figure 6. Test 1, Response spectra for Z direction at tower top and base.

Table 1: Calculation results for test example 1.

| Calculated data | Excitation direction | ACS SASSI | LS-DYNA | Error, % |
|---|---|---|---|---|
| ZPA at base centre [m/s$^2$] | X | 0.0539 | 0.0518 | -3.9 |
| MSA at base centre [m/s$^2$] | X | 0.2930 | 0.2790 | -4.8 |
| ZPA at top centre [m/s$^2$] | X | 0.2132 | 0.2240 | 5.1 |
| MSA at top centre [m/s$^2$] | X | 2.2460 | 2.4460 | 8.9 |
| ZPA at base centre [m/s$^2$] | Y | 0.0534 | 0.0516 | -3.3 |
| MSA at base centre [m/s$^2$] | Y | 0.2420 | 0.2360 | -2.5 |
| ZPA at top centre [m/s$^2$] | Y | 0.0951 | 0.0921 | -3.1 |
| MSA at top centre [m/s$^2$] | Y | 0.4880 | 0.4810 | -1.4 |

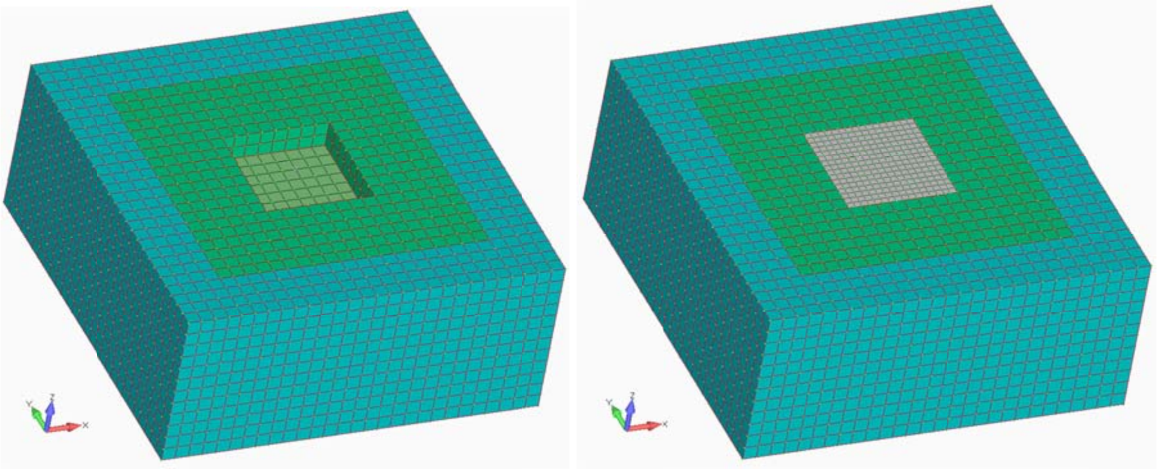
## TEST EXAMPLE 2

For the second test example, a problem of calculating seismic response of a site with improved soil (IS) massif with dimensions in plan 80 x 80 m and a depth from the surface of 20 m, located in the environment of the original soil, was used. Improved soil parameters: $E = 1.089 \cdot 10^{10}$ N/m$^2$, $\mu = 0.3174$, $\rho = 2452$ kg/m$^3$ (Vs = 1300 m/s, Vp = 2500 m/s). Parameters of the surrounding initial soil: $E = 1.629 \cdot 10^9$ N/m$^2$, $\mu = 0.1531$, $\rho = 2000$ kg/m$^3$ (Vs = 400 m/s, Vp = 900 m/s).

It was required to determine the seismic response on the surface of the improved soil massif for a point located in the centre of the massif. An accelerogram of the original soil surface motion was used as seismic input. The calculation was carried out separately for two directions of excitation - horizontal (X) and vertical (Z).

The computational model presented in Figure 7 consisted of a three-dimensional soil model surrounded by PLM-type elements simulating non-reflecting boundaries. In the soil model, a recess (excavation) was created, in which the IS model was located. The soil and IS models had independent finite element meshes connected to each other only using the contact conditions specified by the *INTERFACE_SSI command.

Figures 8 and 9 show resulting response spectra at the center of IS soil massif for X and Z directions. It shows good agreement for X direction and less accurate results for Z direction for which higher response in the range of 2 – 7 Hz was calculated using LS-DYNA.



**a)** **b)**

Figure 7. Calculation model for test example 2; a) excavation, b) excavation filled with IS.

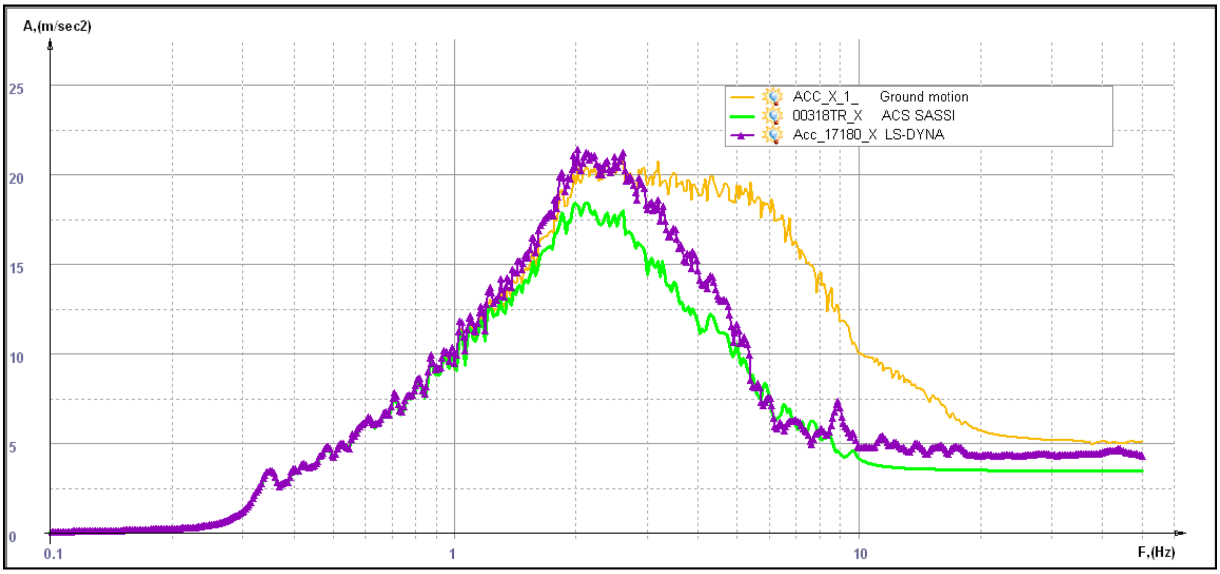


Figure 8. Test 2, response spectra for X direction.

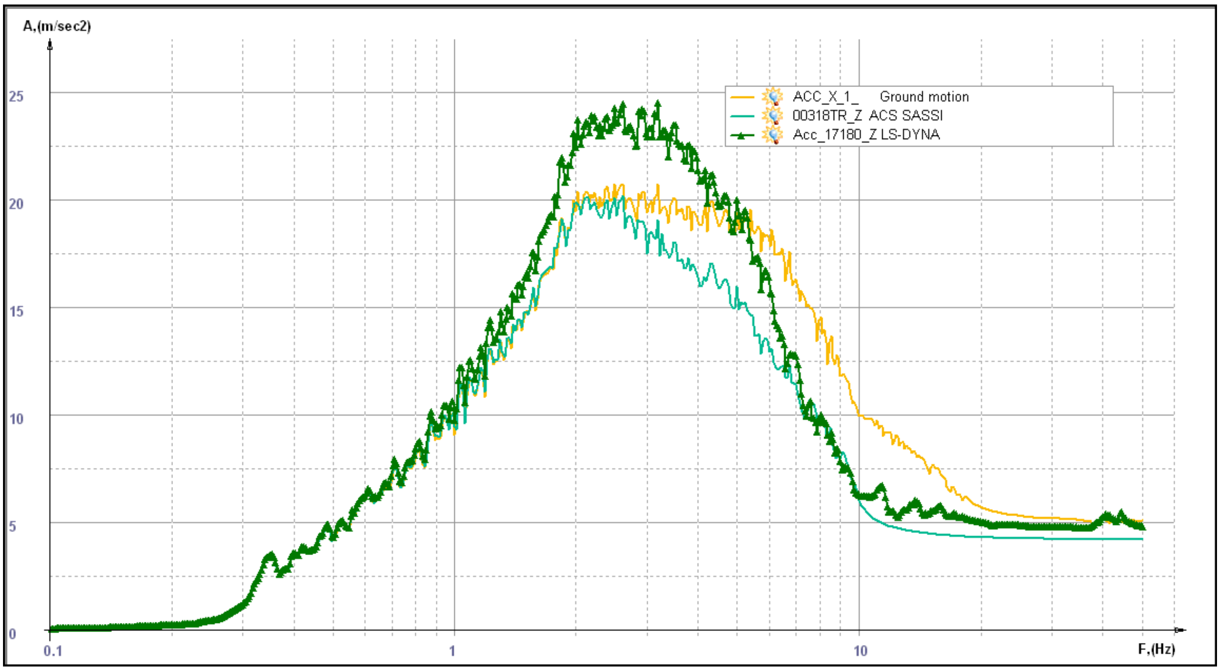


Figure 9. Test 2, response spectra for Z direction.

An additional test was performed with homogeneous soil, i.e. with IS properties set equivalent to the surrounding soil properties. In this case the response at the center of IS soil massif must be equivalent to the ground response spectra. As shown in the figure 10 discrepancies up to 22 % at the maximum spectral acceleration and up to 40% in the frequency range of 4-8 Hz were found.

Results for the second example are summarized in table 2. It shows a higher discrepancy between the calculation methods as compared to the first example.

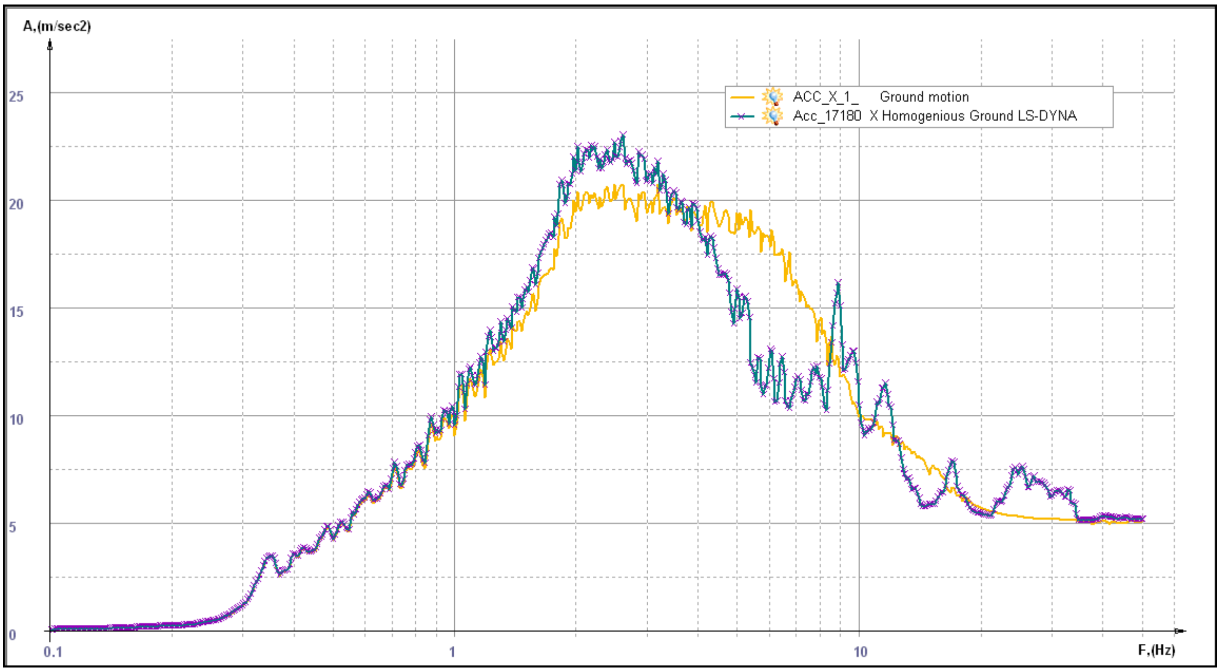


Figure 10. Test 2, homogeneous soil, response spectra for X direction.

Table 2: Calculation results for test example 2.

| Calculated data | Excitation direction | ACS SASSI | LS-DYNA | Error, % |
|---|---|---|---|---|
| ZPA [m/s$^2$] | X | 3.42 | 4.25 | 24.5 |
| MSA [m/s$^2$] | X | 18.39 | 21.19 | 15.2 |
| ZPA [m/s$^2$] | Z | 4.18 | 4.71 | 12.8 |
| MSA [m/s$^2$] | Z | 20.09 | 24.46 | 21.8 |
| ZPA at base centre [m/s$^2$] | Y | 4.98 | 5.08 | 2.1 |
| ZPA homogeneous soil [m/s$^2$] | X | 20.73 | 22.25 | 7.3 |
| MSA homogeneous soil [m/s$^2$] | X | 3.42 | 4.25 | 24.5 |

## CONCLUSION

Verification of the effective seismic input method implemented in the LS-DYNA software resulted in good agreement with results obtained using the control solution. In the case of surface structure, the maximum error in response spectra calculation is less than 10 %. For the embedded structure, less accurate but more conservative results were obtained, with the maximum error of 24.5 % in the calculation of ZPA.

## REFERENCES

Hallquist, J. O. (2015). LS-DYNA Keyword User's Manual R8.0 03/23/15 (r:6319). Livermore Software Technology Corporation, California, USA.

Basu, U. (2009). "Explicit finite element perfectly matched layer for transient three-dimensional elastic waves." International Journal for Numerical Methods in Engineering, 77(2), 151-176.

LSTC, Livermore Software Technology Corporation (2017). Soil-Structure Interaction description, https://www.lstc.com/applications/soil_structure

Ghiocel Predictive Technologies, Inc. (2016). "ACS SASSI-An Advanced Computational Software for 3D Dynamic Analyses Including SSI Effects", ACS SASSI Version 3 (IKTR8) User Manuals, December, Rochester, NY, USA