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PROGNOSIS AND ASSESSMENT OF VIBRATION PROPAGATION DUE TO BLAST DEMOLITION

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ABSTRACT

In the present paper, a methodological framework is proposed to predict ground vibrations resulting from structural demolition by explosive blasting using numerical simulations combined with vibration measurements. The aim is to examine how the predicted ground vibration responses affect the infrastructures close to the vibration source and to assess potential structural damage that may be induced. Based on the proposed methodology, free field response spectra due to the vibration excitation are generated at the location of the nearby structures and are compared to the free field seismic design spectrum at the site for different plant condition levels according to the nuclear safety standards. As a case study, the demolition of a cooling tower of a nuclear power plant (NPP) in Germany is investigated and the effects at the nearby technical facilities (i.e. Emergency Diesel Generator: EDG) are evaluated.

INTRODUCTION

In the decommissioning phase of NPP, structures may be dismantled while safety-related SSC (systems, structures, components) are still in operation. Blast demolition is an economic procedure for dismantling with low emissions especially of conventional or decontaminated structures. However, resulting vibrations at safety-related SSC need to be predicted and assessed.

There are generally two main approaches, which can be used to predict and assess vibration propagation due to blast demolition. The first one is based on exploiting onsite measurements of past demolition events of similar structures whereas in the second one numerical simulations are performed so that the actual local site characteristics are taken into account.

In this paper, a methodological framework is proposed aiming at predicting and assessing the ground vibrations due to blast demolition, combining the numerical simulation with vibration measurements from past demolition events. In the proposed approach, the finite element method is used for the prognosis in consideration of the actual dynamic characteristics of the soil profile. In order to examine the impact of the vibration propagation on structures located close to the demolition source, free field response spectra due to the induced ground vibration are evaluated by comparing them with the site-specific seismic design spectrum. According to nuclear safety standard KTA 2201.6, two plant condition levels are considered: the “inspection level” and the “shut-down level” which are equal to 0.4 and 0.6 times the design basis earthquake (DBE) respectively. Blast demolition is considered as an operational load case. Thus, for plant structures designed with seismic provisions, the required operational safety level is provided if the resulting acceleration response spectra values at the location of interest (50% confidence interval) are not exceeding the 0.4·DBE (inspection level). The robustness of the procedure is enhanced by evaluating also the “extreme” scenario, for which the resulting acceleration response spectra values (95% confidence interval) are not exceeding the 0.6·DBE (shut down level).

In order to highlight the proposed methodology, the demolition of a hyperbolic cooling tower of a nuclear power plant (NPP) in Germany is addressed as a case study. The effects of the resulting ground vibrations on the Emergency Diesel Generator building located close to the tower are evaluated.

DEVELOPMENT OF FREE FIELD RESPONSE SPECTRA BASED ON NUMERICAL SIMULATION

Methodological framework and case study

The proposed methodology is implemented to investigate the effects of ground vibrations induced by the demolition of a hyperbolic cooling tower of a NPP in Germany. More specifically the effects on the EDG building located at a distance of approximately 314 m close to the tower are predicted and assessed.

The vibration predictions are based on the numerical simulation of a free-field soil model and assuming that vibration is generated by a point source. The numerical modelling is conducted using the program SASSI2000 which performs dynamic analyses in the frequency domain including the subsoil characteristics (layered half-space).

Under the implementation of a harmonic excitation, transfer functions from the vibration centre (i.e. cooling tower) to the location of interest (i.e. EDG building) are generated in horizontal and vertical direction. The transfer functions are then combined with real free field recordings from past demolition events of similar cooling towers in order to represent on a reliable basis the ground vibration due to the dynamic impact loading. More specifically recorded time histories are used as reference input introduced in the simulation at a distance from the vibration source, which corresponds, to the actual distance of the respective demolition event. The reference input signals are scaled to reflect the predicted maximum free field vibration velocity at the respective real distance. Two scaling levels of the maximum predicted vibration velocity are considered: the first corresponds to the 50% ($v_{max,\ 50\%}$) and the second to the 95% ($v_{max,\ 95\%}$) confidence interval representing the “operational” and the “extreme” load case scenario respectively. Finally, the resulting mean and median response acceleration spectra for the EDG building (in free field condition) are compared to the site-specific seismic design spectra in horizontal and vertical direction.

This approach allows the consideration of the site-specific propagation properties of the soil medium as well as the attenuation of the high frequency waves with distance. Thus, effects such as the decrease of maximum vibration velocity with increasing distance and the expected attenuation of high-frequency vibration components are taken into account in the wave propagation analysis.

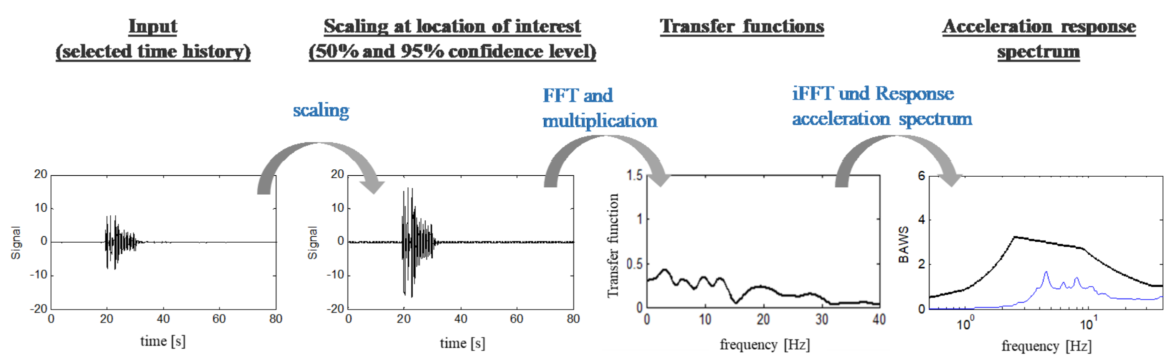

Figure 1. Prognosis of vibration prognosis due to blast demolition based on numerical simulation (SASSI)

Soil modelling

The simulation of the soil medium as well as the soil wave propagation analysis are performed with SASSI2000 (a System for Analysis of Soil-Structure Interaction). In SASSI the site is considered to consist of semi-infinite horizontal layers on a semi-infinite elastic half-space. The soil is modelled in three dimensions and linear elastic behaviour is considered. In order to investigate the soil wave propagation the dynamic characteristics of the medium are required. In the present study, the shear wave velocities of the different soil layers are defined at first based on the available geotechnical surveys and are continuously updated based on field measurements performed at site.

According to the available geotechnical survey the soil profile characteristics consists of various silty and sandy gravel layers:

- ± 0.0 (soil ground level) – 2.5 m — Soft soil deposits
- 2.5 m – 10.0 m — Sand gravel
- 10.0 m – 50.0 m — Silty fine and medium sands
- 50.0 m – 90.0 m — Sandy and clayey silts
- 90.0 m – 120.0 m — Silt and sand with gravel
- > 120.0 m — Sequences of sand, silt, clay, gravel

The damping level range is defined as D = 7% – 9.5% for a shear deformation level approx. 0.02%. The dynamic soil parameters (Vs: shear wave velocity; γ: soil unit weight; ν: Poisson ratio; G_{dyn}: dynamic shear modulus) are summarized in Table 1.

Table 1: Dynamic parameters of the soil profile based on the geotechnical survey

Depth [m]	Vs [m/s]	γ [kN/m³]	ν [-]	G_{dyn} [kN/m²]
0 – 3.5	100	18	0.44	18000
3.5 – 6.0	230	18	0.21	95000
6.0 – 10.0	230	18	0.49	95000
10.0 – 16.0	230	19	0.49	100000
16.0 – 30.0	375	19	0.48	267000
30.0 – 50.0	430	19	0.47	351000
> 50.0	570	19	0.45	617000

Field measurements are performed on site in order to validate and update the dynamic soil parameters provided by the past geotechnical surveys. This can be achieved through free- or forced vibrations tests (mass vibrator system: shaker), which lead to the excitation of shear waves and Rayleigh waves thus allowing the determination of the shear wave velocities and damping values. The dynamic properties can be defined experimentally for a specific soil depth, which depends on the excitation frequency of the shaker. Additionally, experimental transfer functions can be extracted that can be used to update the numerical model in order to extract “numerical” transfer function comparable to the experimental ones.

In the present study, the dynamic characterization of the site was achieved up to a soil depth of approximately 13.5 m, using a shaker vibration test system. The average shear wave velocity of the upper soil layers and the corresponding damping values were estimated about 210 m/s and 5.7% respectively. Transfer functions deduced experimentally were also compared to the numerical ones (Figure 2) and the soil dynamic parameters were further updated in order to achieve a good comparison.

Table 2 represents the final dynamic soil properties emerged from the combination of the past geotechnical survey and the on site field experiments. For the damping, a value of 3% was found to represent best the experimental data. These values, summarized in Table 2, are adopted for the further analyses. It should be noted herein that the adopted damping value of 3% is conservative since higher vibration amplitudes and hence higher damping values are expected in the case of blasting demolition compared to the shaker tests.

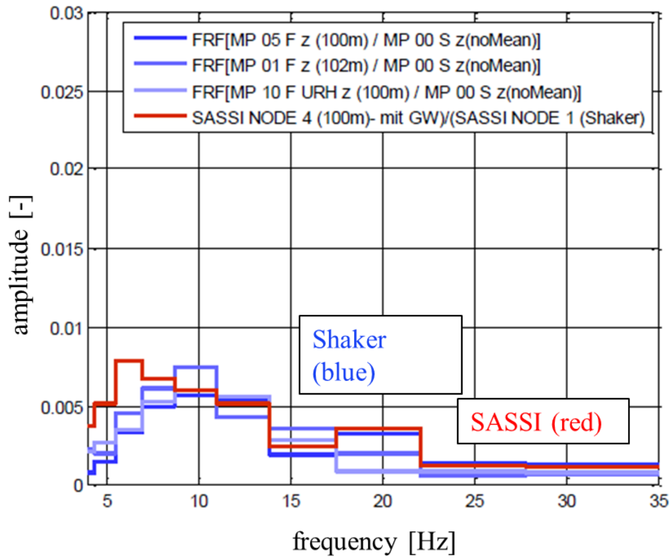

Figure 2. Comparison of experimentally (shaker) and numerically (SASSI) determined transfer functions at a distance of 100 m

Table 2: Updated dynamic parameters of the soil profile based on the field measurements

Depth [m]	Vs [m/s]	γ [kN/m³]	ν [-]	G_{dyn} [kN/m²]
0 – 3.5	215	19	0.44	88000
3.5 – 6.0	215	19	0.21	88000
6.0 – 10.0	215	19	0.49	88000
10.0 – 16.0	229	19	0.49	100000
16.0 – 30.0	375	19	0.48	267000
30.0 – 50.0	430	19	0.47	351000
> 50.0	570	19	0.45	617000

Free field response spectra

After the determination of the soil dynamic properties, wave propagation analyses are performed with SASSI. The aim is to use the resulting transfer functions to generate the free field response spectra due to the vibration excitation. In order to simulate the ground vibration from the dynamic impact on a reliable basis, recorded data from measured vibration from past demolition events of similar cooling towers are used as reference records, which include the unknown excitation signal. In total 9 reference recordings were used. These reference records are introduced in the model on the connection line between the vibration centre and the nearby structure (i.e. EDG building) at a distance respective to the one they had at the actual demolitions. At these "entry nodes" the recorded signals are scaled to correspond to the maximum value of free field vibration velocity at the respective real distance. As stressed previously, two scaling levels of the maximum predicted vibration velocity are considered: the first corresponds to the 50% ($v_{max,\,50\%}$) and the second to the 95% ($v_{max,\,95\%}$) confidence interval respectively. The scaled time signals are multiplied in the frequency domain with the transfer functions of the soil that have been generated with respect to the "entry nodes". Finally, the new velocity signals are used to derive in time domain the acceleration time histories and to extract the acceleration response spectra. Figures 4 and 5 show the acceleration response spectra of different reference records used in the procedure as well as the resulting mean and median acceleration response spectra for the 50% and 95% scaling level in horizontal and vertical direction respectively.

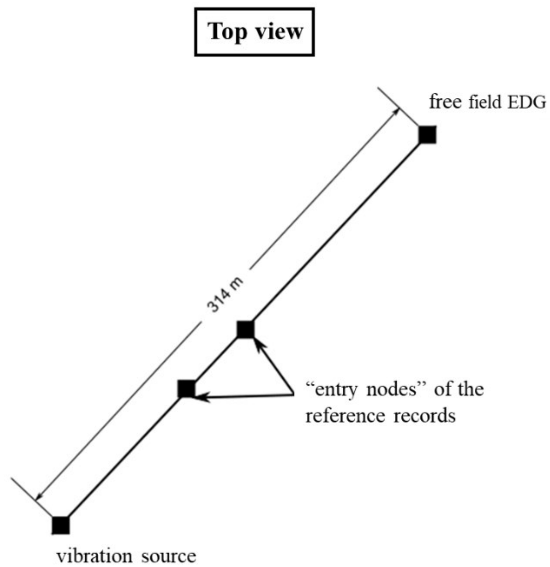

Figure 3. Schematic depiction of the numerical model of the vibration propagation

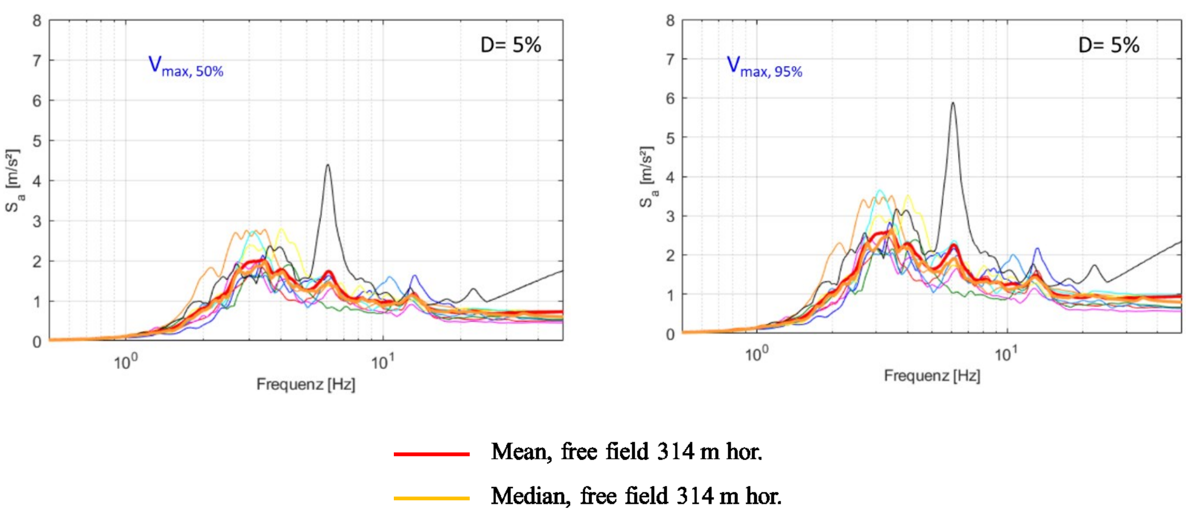

Figure 4. Free field response spectra for free field "entry nodes" in horizontal direction based on the $v_{max,\ 50\%}$ scaled time history recordings (left) and the $v_{max,\ 95\%}$ scaled

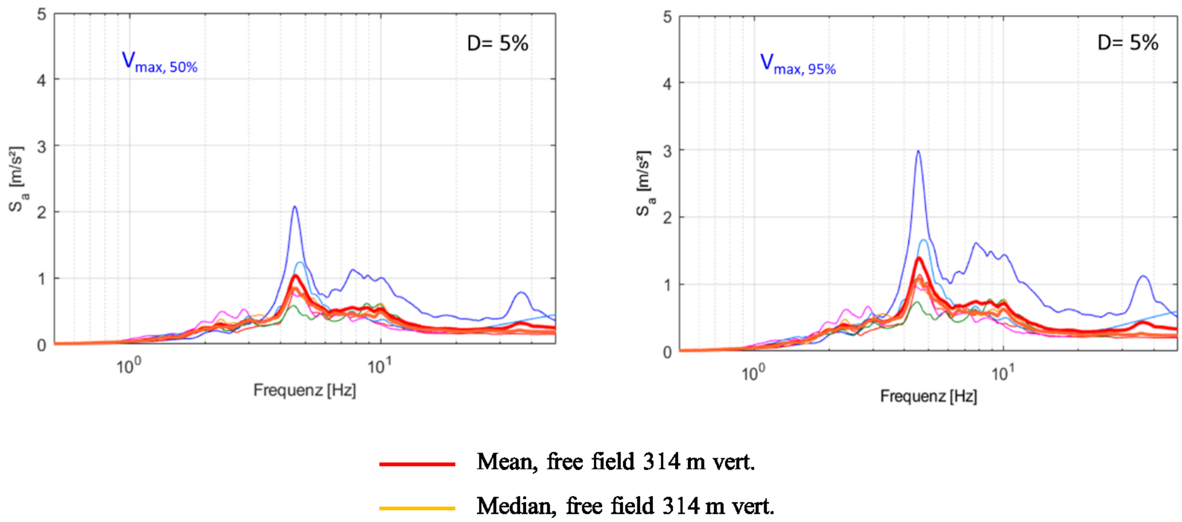

Figure 5. Free field response spectra for free field "entry nodes" in vertical direction based on the $v_{max,\ 50\%}$ scaled time history recordings (left) and the $v_{max,\ 95\%}$ scaled

DAMAGE EVALUATION OF NEARBY INFRASTRUCTURES

To evaluate possible damage on the nearby infrastructure the corresponding free field response spectra are compared to the free field seismic design spectrum at the site. Based on KTA 2201.6 two plant condition levels are considered: the "inspection level" and the "shut-down level" which are equal to 0.4 and 0.6 times the design basis earthquake (DBE) respectively. The median and mean response spectra for the $v_{max,50\%}$ and $v_{max,95\%}$ scaling levels are compared to the 0.4·DBE and 0.6·DBE response spectra respectively and no structural damage is expected if the computed response spectra lie under the DBE ones. Figures 6 to 9 show the comparison between the median / mean horizontal and vertical free field spectra at the EDG building with the DBE response spectrum for the "operational" (v50%) and the "extreme" (v95%) load case scenario. For both scenarios the resulting mean and median acceleration response spectra values are not exceeding the required DBE levels in both horizontal and vertical directions.

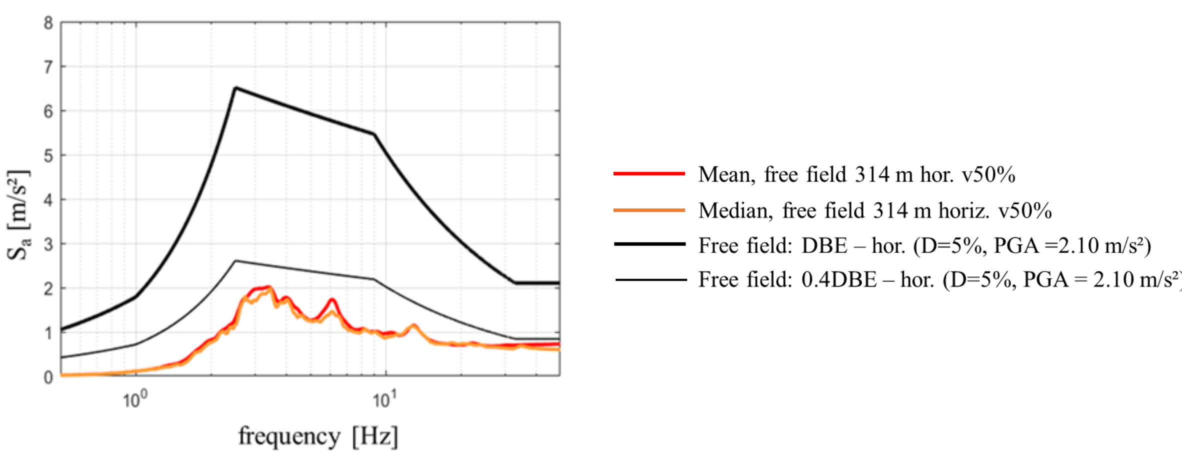

Figure 6. Comparison of the computed median/mean horizontal free field spectra v50% at the structure and the 0.4·DBE response spectrum

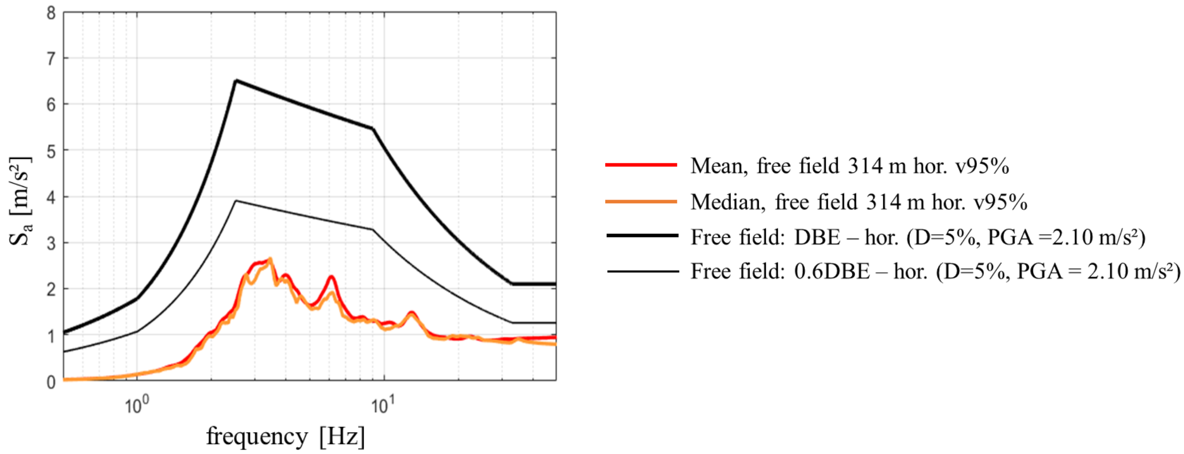

Figure 7. Comparison of the computed median/mean horizontal free field spectra v95% at the structure and the 0.6·DBE response spectrum

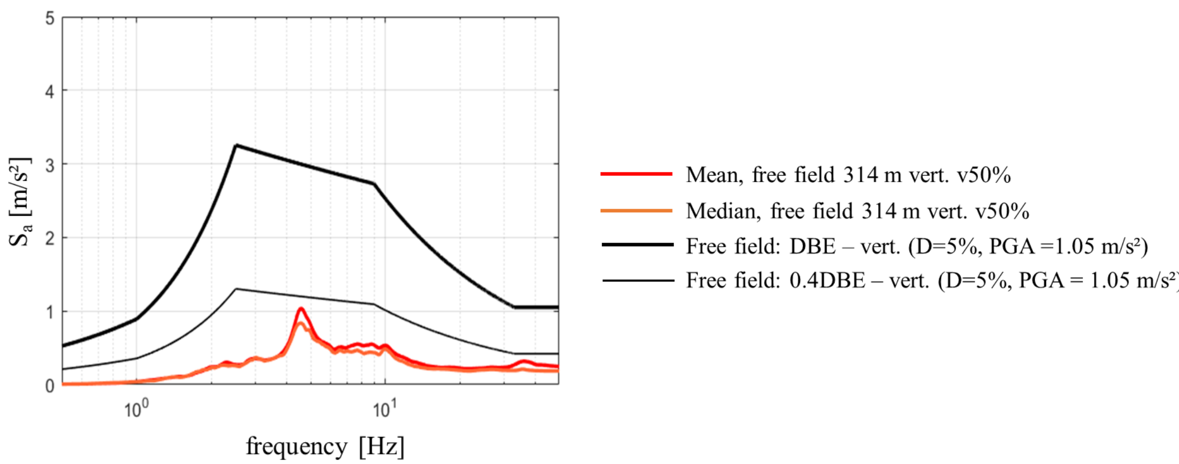

Figure 8. Comparison of the computed median/mean vertical free field spectra v50% at the structure and the 0.4·DBE response spectrum

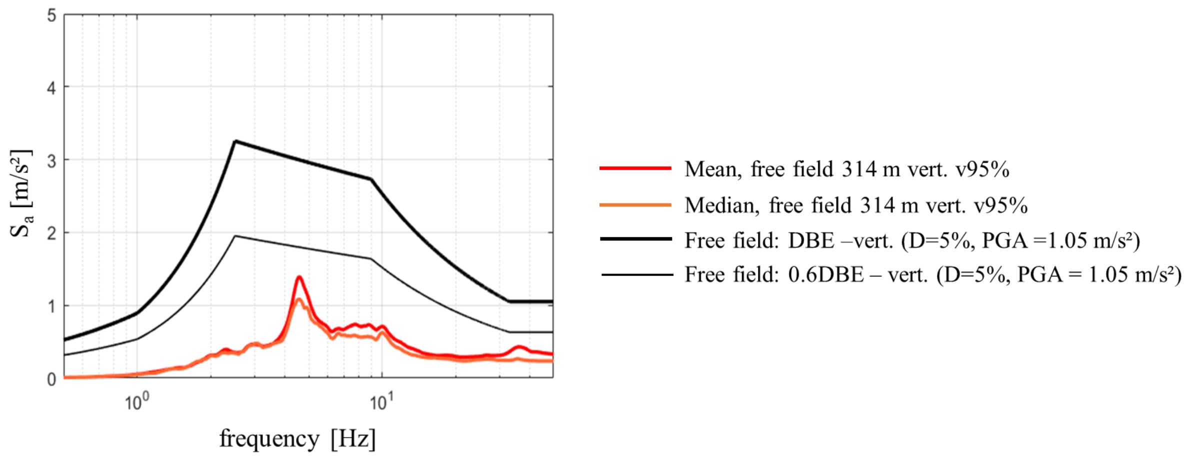

Figure 9. Comparison of the computed median/mean vertical free field spectra v95% at the structure and the 0.6·DBE response spectrum

CONCLUSION

In this study, a methodological framework is proposed that can be implemented to predict ground vibrations due to structural demolition induced by explosive blasting. As a case study, the demolition of a cooling tower of a NPP in Germany was investigated and the effects on the Emergency Diesel Generator building, located at a close distance to the vibration source, were evaluated. A three dimensional numerical model of the soil medium in free field conditions was analysed. The available dynamic soil properties from past geotechnical surveys were updated based on onsite field measurements. With the numerical approach, the site-specific propagation properties of the soil medium as well as the attenuation of the high frequency components with increasing distance were taken into account in the wave propagation analysis.

The numerical simulations were combined with vibration measurements from past demolition events to generate free field response spectra at the location of the EDG building. The potential structural damage on the building was assessed by comparing the generated free field response spectra to the site-specific free field seismic design spectrum for different plant condition levels according to KTA 2201.6. It was shown, that for both the “inspection level” and the “shut-down level”, the required safety levels for the EDG building in case of the demolition of the nearby cooling tower was provided.

Overall, this paper provides a robust methodological framework, which can be used as a structural assessment tool to evaluate ground vibration effects induced by structural demolition by explosive blasting.

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