SEISMIC RESPONSE ANALYSIS CONSIDERING WAVE PASSAGE

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SUMMARY

Present state-of-the-art seismic analysis methods neglect the passage of seismic waves by typically relying on the assumption that every point of a structural foundation receives identical excitation. Phase differences in seismic excitation are considered as negligible owing to foundation plan dimensions being small compared to seismic wavelengths for most practical structures. However, as foundations increase in plan dimensions through the use of continuous mats for multiple structures of a nuclear power plant, they become of the same order as seismic wavelengths such that neglecting phase differences in excitation at various points can lead to unconservative structural response.

The mechanism by which the seismic waves affect the response characteristics through consideration of phase differences in excitation is twofold. First, phase differences resulting from the passage of surface Rayleigh waves can lead to excitation of rocking structural modes above that due to the coupling of rocking and horizontal translational modes. Second, phase differences resulting from the passage of surface Love waves and seismic shear waves can lead to excitation of torsional structural modes even in rotationally symmetric structures. This latter phenomenon can lead to the largest errors in seismic response since typically no torsional modes are considered excited in typical nuclear structures, especially reactor and containment vessels.

Present methods of response spectra analysis rely on a set of damped smooth ground response spectra as part of the design criteria for nuclear power plants which are only available for three translational excitation directions, thereby assuming that every point receives identical excitation for a given direction. Including wave passage effects in the seismic design criteria for structures with mat dimensions of the same order as seismic wavelengths would lead to three additional response spectra resulting from rocking excitation about the two horizontal axes and torsional excitation about the vertical axis. Also, the coupling between rocking and translation would lead to translational spectra resulting from rotational excitation. Unlike the translational design spectra, which are independent of the geometric aspects of a structure, rotational and translational spectra resulting from rotational excitation would be highly dependent upon the geometric characteristics of the structure. This results from the rigid body transformations of rotational excitation into both rotational and translational response dependent upon the locations of mass centers compared to excitation points.

One method of resolving the problem of specifying design rotational and translational response spectra resulting from rotational excitation is discussed in detail in the paper. The method consists of predicting the phase difference expected between various points on a foundation mat based on comparisons of mat plan dimensions to be predicted wavelengths such that at each excitation point the ground acceleration can be written as $a(t)\cos(w)$ where $d(\omega)$ is the phase difference as a function of frequency based on comparisons of the seismic wavelengths and mat dimensions since the wavelength varies inversely with frequency. Considering the phase difference in the spatial distribution of seismic excitation, it is shown that it can be included in the determination of the seismic modal participation factors such that only translational response spectra need to be defined in the seismic design criteria.

Utilizing standard matrix equations of motions for multiply connected structures based on the displacement method of analysis, expressions are presented for the seismic participation factors including the effect of wave passage by means of the phase factor discussed above. Participation factor comparisons, with and without wave passage effects, plus results of seismic analyses are presented.