3D Locally Resonant Periodic Foundations with Low Frequency Band Gaps for Seismic Protection of Fuel Storage Tanks

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Abstract

Fluid-filled tanks in tank farms of industrial plants can experience severe damage and trigger cascading effects in neighbouring tanks due to the large vibrations induced by strong earthquakes. In order to reduce tank vibrations, we have explored an innovative type of foundation, designed by metamaterial-based concepts. Metamaterials are generally regarded as manmade structures that exhibit unusual responses not readily observed in natural materials. They were first introduced in the field of electromagnetic and acoustic wave propagation. If properly designed, in fact, they are able to stop or attenuate wave propagation effects. On the other hand, recent studies have shown that if locally resonant structures are periodically placed in the matrix material, the resulting metamaterial also forms a phononic lattice material that creates a stop band, which forbids elastic wave propagation within the bandgap frequency range. Moreover, differently from conventional phononic lattice structures for which gigantic unit cells are required for low-frequency vibration shielding, locally-resonant metamaterials can enjoy the lattice constant of the crystal to be much smaller than the longitudinal wavelength of the propagating wave.

Along this line, we have investigation 3D periodic foundations with effective attenuation zones conceived as vibration isolation systems for storage tanks. Based on common construction materials, concrete and rubber, the three-component periodic foundation cell has been developed. Frequency band gaps, computed using the Bloch-Floquet's theorem, have been found to be wide and in the low-frequency region, i.e. below 10Hz. A parametric study has been also conducted to illustrate the influences of the geometrical and material parameters on the frequency band gaps. Based on the band gaps analysis, numerical simulations have been performed to verify the efficiency of the periodic foundation. Harmonic analysis results have shown that periodic foundations can effectively reduce vibrations in the frequency band gap. Finally, a transient analysis of the whole 3D structure-foundation model has pointed out that 3D periodic foundations can also effectively isolate realistic seismic waves and reduce stresses in tanks.