Reduction of earthquake amplification by seismic metamaterials made of circular positioned concrete piles

Selcuk Kacin[1], *Murat* Ozturk[1], *Umur* Sevim[1], *Muharrem* Karaaslan[2*], *Oguzhan* Akgol[2], *Zafer* Ozer[3], *Mustafa* Demirci[1], *Emin* Unal[4], *Bayram* Mert[5], *Mustafa* Başar[6]

[1]Iskenderun Technical University, Dept. of Civil Eng., Hatay, 31200, Turkey, 31200, Turkey
[2]Iskenderun Technical University, Dept. of Electrical and Electronics Eng., Hatay, 31200, Turkey
[3]Mersin University, Vocational School of Mersin, Dept. of Electronics Tech., Mersin, 33350,
[4]Necmettin Erbakan University, Electrical and Electronics, Konya, 42090,
[5]Iskenderun Technical University, Iskenderun Vocational School, Hatay, 31200, Turkey
[6]Iskenderun Technical University, Dept. of Mechanical Eng., Hatay, 31200, Turkey

Abstract. Seismic surface waves with low frequencies results in higher effects. The aim of the utilization of seismic metamaterials is to prevent or minimize the effects of this waves particularly wide frequency ranges. This study presents the investigation of the reducing effects of seismic metamaterials composed of circular array concrete piles on surface waves. The investigation of circular array concrete piles has been carried out numerically between 5-15 Hz. The effectiveness of the periodic structure has been observed numerically for fields including metamaterials by comparing empty field. The observations have been depicted according to transmission losses for two cases by using finite element method (FEM) simulations. The wave propagation also presented at the related frequencies where the transmission losses seen. Effective dimensions of radius and length of the structures have been obtained by using parametric approach. It has been proved numerically that the suggested concrete piles reduces the hazardous effects of surface waves.

1 Introduction

Seismic surface waves with low frequencies results in higher effects [1, 2, 3]. The aim of the utilization of seismic metamaterials is to prevent or minimize the effects of this waves particularly wide frequency ranges. This study presents the investigation of the reducing effects of seismic metamaterials composed of circular array concrete piles on surface waves. The investigation of circular array concrete piles has been carried out numerically between 5-15 Hz. The effectiveness of the periodic structure has been observed numerically for fields including metamaterials by comparing empty field.
The observations have been depicted according to transmission losses for two cases by using finite element method (FEM) simulations [4, 5]. The wave propagation also presented

* Corresponding author: muharrem.karaaslan@iste.edu.tr

at the related frequencies where the transmission losses seen [6]. Effective dimensions of radius and length of the structures have been obtained by using parametric approach [7]. It has been proved numerically that the suggested concrete piles reduces the hazardous effects of surface waves [8].

Seismic metamaterials have emerged as a novel approach to mitigate low-frequency waves within the resonance frequency range of 1-10 Hz [9]. Inspired by the vibration damping properties of forests, Liu et al. [10] utilized trees as large-scale natural metamaterials to dampen low-frequency vibrations. Miniaci et al. [11] explored the potential of large-scale mechanical metamaterials for passive isolation, impacting both surface and guided waves. Pu and Shi [12] investigated the behavior of surface waves in one- and two-dimensional periodic structures, demonstrating the effectiveness of a finite periodic pile system in attenuating waves.

This study investigates the effectiveness of seismic metamaterials formed by placing concrete piles in a circular array to prevent surface waves. The proposed structure was analysed theoretically using a finite element method (FEM)-based analysis program. The study was conducted in both the frequency and time domains, with a focus on the low-frequency range, which poses a threat to structures. The proposed structure shows promise as an effective method for mitigating the propagation of seismic surface waves and could be considered for use in earthquake research.

2 Theory and numerical analysis

In this study, the numerical analysis has been carried out by using finite element method (FEM) based simulator. The circular arrangement of concrete piles based seismic metamaterials has been assigned in the field of simulation as can be seen in Figure 1.

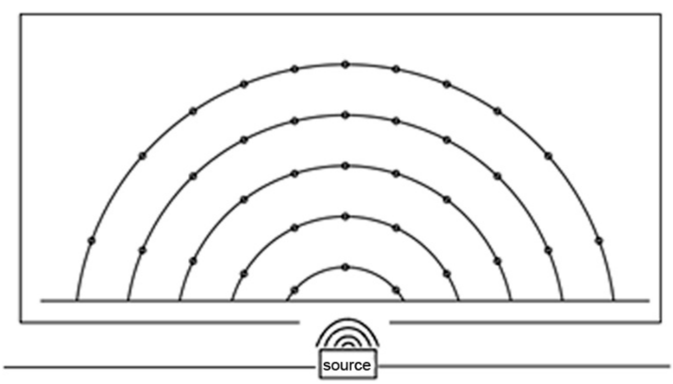
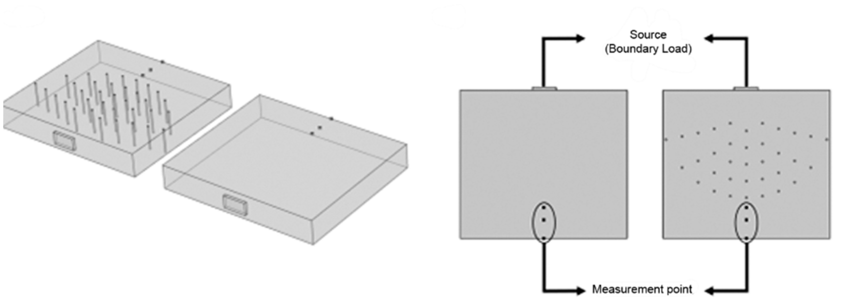


Fig. 1. Concrete piles in circular arrangement.

The length and radius of the concrete piles has been evaluated by using parametric approach. The effective values of the radius and length of the concrete piles have been determined as 7.5cm and 2m, respectively. Since the non-periodical arrangement of the piles, the band diagram of one unit cell cannot be extracted. The Young's modulus of the soil is assigned as 20 MPa, the poisson's ratio defined as 0.3 and the density is denoted as 1800 kg / m3, the Young modulus, the poisson's ratio and the density are assigned as 30 GPa, 0.25 and 2500 kg / m3, respectively. All these values are obtained from the field analysis and measurement results of the soil. The observation of the effectiveness of the proposed concrete piles has been realized by comparing the results of soil with and without concrete piles in circular array. The overall system has been depicted in Figure 2.

https://doi.org/10.1051/e3sconf/202340403006



a) b)

Fig. 2. a) Fields with and without concrete piles b) measurement points and boundary loads.

1 N test signal has been applied to sample fields in simulations for both frequency and time domain cases. The frequency range has been defined between 5-15 Hz which is highly destructive characteristics. The applied signals have been depicted in Figure 3 in frequency and time domain.

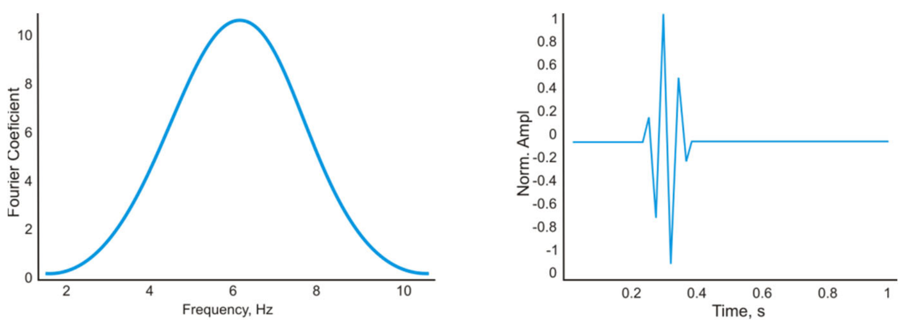


Fig. 3. Applied pulses in frequency and time domain.

The transmission losses in terms of dB for concrete piles with respect to empty field have been demonstrated in Figure 4. Six resonance frequency points have been observed between 5-15 Hz. The resonance frequencies and transmission loses for them are 5.1 Hz, 6.2 Hz, 6.5 Hz, 8.5 Hz, 11.2 Hz, 12.3 Hz, 13.8 Hz and 14 Hz, -16 dB, -11.73 dB, -20.6 dB, -13.3 dB, -23.28 dB, -28.1 dB, -18.85 dB, -37.82 dB, respectively.

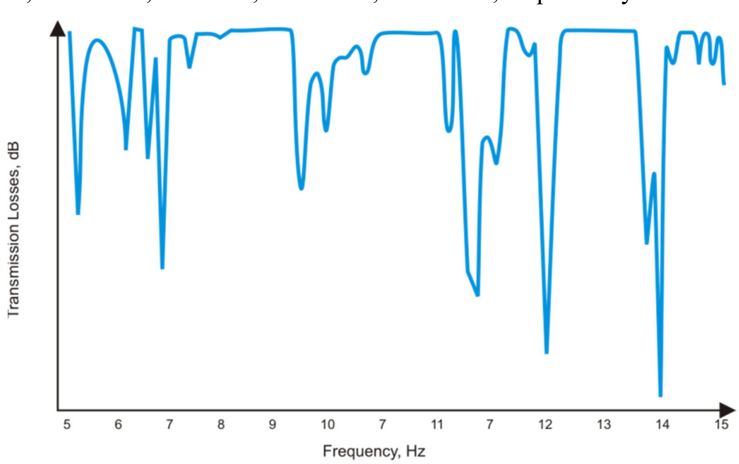


Fig. 4. Transmission Values in dB.

The propagation of the applied vibration in the field with and without metamaterials has been given in Figure 5 for each resonance frequencies mentioned above. Hence, it can be possible to compare the effectiveness of the concrete pills and circular arrangement.

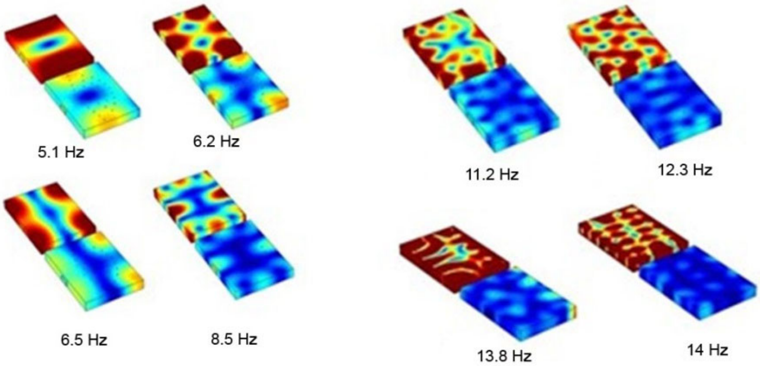
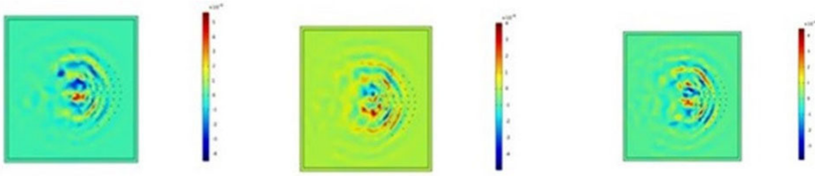


Fig. 5. Total displacement with and without boreholes at resonance frequencies.

The simulations have been realized for each resonance frequency, since the transmission coefficients are not equal for different cases. The maximum and minimum displacements scales have been demonstrated by red and blue colours. As can be seen from the results, the propagation of vibration reduces behind the metamaterial structures.

The simulations have also been carried out in time domain at the related resonance frequencies by using finite element method based simulator. Since the surface waves propagate perpendicular to concretes, the reduction characteristics of waves investigated in x-y plane. Besides, the horizontal component of the applied waves along x direction resonates with concrete piles. The phase difference between incident and reflected vibrations results in reduction of propagating wave in resonance case. The responses of the periodic structure against surface wave for three discrete frequencies have been depicted in Figure 6.



a) b) c)

Fig. 6. a) 2D displacement at 6.5 Hz b) 2D displacement at 8.5 Hz c) 2D displacement at 14 Hz.

Upon analysing wave propagation at specific frequencies within the field incorporating concrete piles, it has been observed that the waves experienced damping after passing through three rows of holes. The wave gradually weakened as it propagates and ultimately failed to pass beyond the proposed structure. The numerical studies conclusively determined that the seismic metamaterial formed by concrete piles arranged in a circular array effectively decreases seismic waves.

3 Conclusion

In this study, circularly arranged concrete piles based seismic metamaterials has been proposed to confine the propagation of vibrations. The simulations have been carried out by using finite element based simulator in the frequency range of 5-15Hz. This frequency range has been chosen due to strong destructive properties. The optimum dimensions of the piles have been determined by using parametric approach. The analysis has been realized for field including concrete piles and the transmission results have been compared with field without piles. The simulation results demonstrated that the periodic structure has capability to reduce propagating wave at the frequencies of 6.5 Hz, 8.5 Hz and 14 Hz. The transmission losses for the resonance frequencies of 6.5 Hz, 8.5 Hz, and 14 Hz are -20.6 dB, -18.85 dB, -37.82 dB, respectively. Hence, it can be concluded that the proposed structure has capability to prevent seismic wave propagation efficiently especially at the resonance frequencies.

This research was supported by the Disaster and Emergency Management Presidency of Turkey (UDAP-Ç-19-21) for the financial support and presentation support by 2224-A Grant Program for Participation in Scientific Meetings Abroad with application number of 1919B022301764.

References

1. D. W. Prather, S. Shi, J. Murakowski, G. J. Schneider, A. Sharkawy, C. Chen, ... & R. Martin, *Self-collimation in photonic crystal structures: a new paradigm for applications and device development*. Journal of Physics D: Applied Physics, 40(9), 2635 (2007)
2. R. Martínez-Sala, J. Sancho, J. V. S´anchez, V. G´omez, J. Llinares, F. Meseguer. *Sound attenuation by sculpture*. Nature;378:241 (1995)
3. R. Zhu, X. N. Liu, G. K. Hu, C. T. Sun, & G. L. Huang, *Negative refraction of elastic waves at the deep-subwavelength scale in a single-phase metamaterial*. Nature communications, 5(1), 1-8 (2014)
4. J. Wen, H. Shen, D. Yu, & X. Wen, *Exploration of amphoteric and negative refraction imaging of acoustic sources via active metamaterials*. Physics Letters A, 377(34-36), 2199-2206 (2013)
5. S. D. Zhao, Y. S. Wang, & C. Zhang, *Acoustic imaging and mirage effects with high transmittance in a periodically perforated metal slab*. Journal of Applied Physics, 120(19), 194901 (2016)
6. S. Gonella, A. C. To, & W. K. Liu, *Interplay between phononic bandgaps and piezoelectric microstructures for energy harvesting*. Journal of the Mechanics and Physics of Solids, 57(3), 621-633 (2009)
7. K. Zhang, C. Zhao, P. Zhao, J. Luo, & Z. Deng, *Wave propagation properties of rotationally symmetric lattices with curved beams*. The Journal of the Acoustical Society of America, 148(3), 1567-1584 (2020)
8. M. Gao, & Z. Shi, *A wave guided barrier to isolate antiplane elastic waves*. Journal of Sound and Vibration, 443, 155-166 (2019)
9. S. Brûlé, E. H. Javelaud, S. Enoch, & S. Guenneau, *Experiments on seismic metamaterials: molding surface waves*. Physical review letters, 112(13), 133901 (2014)
10. Y. F. Liu, J. K. Huang, Y. G. Li, & Z. F. Shi, *Trees as large-scale natural metamaterials for low-frequency vibration reduction*. Construction and Building Materials, 199, 737-745 (2019)
11. M. Miniaci, A. Krushynska, F. Bosia, & N. M. Pugno, *Large scale mechanical metamaterials as seismic shields*. New Journal of Physics, 18(8), 083041 (2016)

12. X. Pu, & Z. Shi, *A novel method for identifying surface waves in periodic structures*. Soil Dynamics and Earthquake Engineering, 98, 67-71 (2017)