Evaluation of waste in seismic metamaterial applications

Volkan Akdogan [1*], *Selcuk* Kacin[2], *Umur* Sevim[2], *Muharrem* Karaaslan[1], and *Mustafa* Başar[3,4]

[1]Iskenderun Technical University, Dept. of Electrical and Electronics Eng., Hatay, 31200, Turkey
[2]Iskenderun Technical University, Dept. of Civil Eng., Hatay, 31200, Turkey, 31200, Turkey
[3]Amasya University, Vocational School of Tasova Yüksel Akin, Department of Motor Vehicles and Transportation Technologies, Amasya, 05800, Turkey
[4]Iskenderun Technical University, Dept. of Mechanical Eng., Hatay, 31200, Turkey

Abstract. Within the scope of this study, a simulation study was carried out in order to prove the usability of waste in seismic metamaterial studies. In the study, a square array field application was preferred, and a 3-layer cylindrical pile design was used. In addition, direct contact of waste with soil and direct air is prevented. Within the scope of the study, polypropylene, which is frequently contained in medical products, concrete as a containment layer, and lime materials to prevent leakage of hazardous waste were used as materials. In addition, a design has been made within the soil structure as the ground structure. As a result of the study, it was determined that transmission losses occur in low frequency regions such as 3-10 Hz values due to obtaining partial band gaps. In addition, when looking at the propagation of the vibration waves in the field plane depending on the time, it is seen that the waves are significantly reduced, and the results are promising.

1 Introduction

Earthquakes are one of the most dangerous natural disasters that have caused many losses of life and property from past to present. Millions of earthquakes occur every year. However, it is known that more than half of the natural disasters experienced are earthquakes [1-3]. Earthquake waves can be described as energy flows that cause rapid agitation on the surface and cause permanent damage to structure by generally spreading in all directions [4]. Seismic metamaterial designs have recently gained significant momentum to reduce the effects of unavoidable earthquakes [5]. Metamaterials are known as materials with superior physical properties, specially designed for engineering applications compared to normal materials, due to their structure [6-8]. First of all, in order to provide seismic insulation, columns, foundations etc. within the structure. The durability of the structure is of great importance in the elements. However, studies show that this can be achieved by using seismic metamaterials regardless of the structure to be protected [9]. Considering the studies carried out to provide seismic isolation, it is seen that optimization studies have

* Corresponding author: volkan.akdogan@iste.edu.tr

been carried out on the physical properties of the materials generally used in designs, the field sequences of the seismic metamaterials and the geometric shapes of the produced metamaterials [10-11]. In this context, when a general evaluation is made, it can be said that numerous designs can be made in seismic metamaterial designs. It is also clear that it is an area of application that needs to be developed effectively. When looking at the materials generally used in seismic metamaterial designs, it is seen that materials such as concrete, steel and rubber, which are widely used in civil engineering, are preferred [12-14].

On the other hand, this situation brings along quite high costs, considering that large pile designs should be made in order to obtain effective results in low frequency bands. Therefore, there is a need for seismic metamaterials that can work efficiently in low-frequency bands economically [15]. This situation supports that waste structures should be used in metamaterial designs as materials. Considering the pandemic conditions that have occurred in recent years in the light of these precursors, a high amount of medical waste has occurred due to Covid-19 [16]. Especially within the scope of this process, the use of masks and the rapid consumption of disposable products such as virus detection kits have triggered the increase in medical waste [17-18]. It is also known that the masks used are produced from various plastic-based polymers and various inorganic materials [19].

In this case, the idea of using waste materials in the contents of metamaterial structures arises. The main idea of this study is to ensure that the waste groups, which usually cause high carbon emissions when they are released to nature or disposed of, can be eliminated by using seismic metamaterials and that seismic vibrations can be reduced with the help of these wastes.

Within the scope of the study, buried pile designs where waste can be safely stored were made. In addition, a lime layer has been added to the design to provide extra protection. Within the scope of the study, the progress of the seismic waves over the created area with time was monitored instantly, depending on the transmission losses obtained in the frequency domain. Studies have been carried out in the frequency range of 3-10 Hz.

2 Material and method

Within the scope of this simulation study, a seismic metamaterial design by using waste has been tried to be realized. Within the scope of this study, physical properties of the plastic derivative polypropylene material as a representation of waste will be included in the simulation studies. The modulus of elasticity, density and poisson ratios of polypropylene and other materials used in the study are shown in Table 1.

Table 1. Materials used in the study and their physical properties [20-24].

Sample	Density	Elasticity module	Poisson ratio
Soil	1800	20e6	0.3
Concreate	2500	30e6	0.25
Limestone	1200	25e9	0.19
Polypropylene	905.32	4e9	0.41

Simulation studies were carried out between 3-10 Hz frequency values. In addition, the impact force of 1 N created within the scope of the study is applied to the structure by creating a 1-second distribution parameter. Time precision was created with a precision of 0.01 seconds. Depending on the frequency and time, the progress of the wave propagation was followed instantly. From the wave source, evaluations were made depending on the progress of the wave distances.

A design was made as shown in Figure 1-a and the positioning of 3-layered circular cross-section cylindrical structures in the soil was realized. The diameter of the circular section filled with the innermost polypropylene was determined as 20 cm, the diameter of the circular section defined as the lime structure immediately surrounding it was determined as 30 cm, and the diameter of the circular equation defined as the outer casing layer was determined as 40 cm. Since hazardous wastes are used here, a layer of lime has been added to the simulation studies. In addition, in order to prevent the contact of the waste structure with air starting from the ground surface, a 20 cm thick square concrete attachment was used to connect the circular structures to each other from the upper part and the contact of the waste structures with air was prevented. The top view of the circular column structures formed in the form of a square arrangement under the concrete square plate is as shown in Figure 1-b. However, looking at the characteristics of a single cell in this square sequence, the unit cell structure in Figure 1-c is obtained. In line with the data obtained here, the direction of the waves is moving as shown in Figure 1-d.

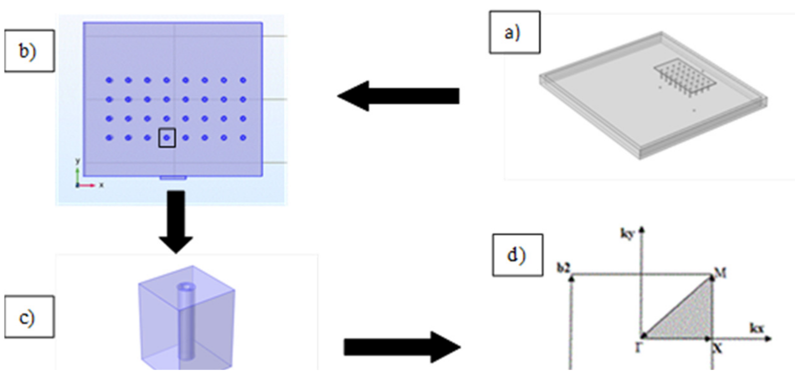

Fig. 1. Within the scope of the study, a) geometric design, b) applied square lattice sequence, c) unit cell structure and d) direction of waves on the unit cell formed.

The wave source was placed at point A at a certain distance from the design realized as shown in Figure 2. With an equal distance to this source, point B from points B and C was placed on the empty earth ground parallel to the source, and point C was placed behind the realized design. Here, the results are evaluated depending on the wave movements at the B and C points.

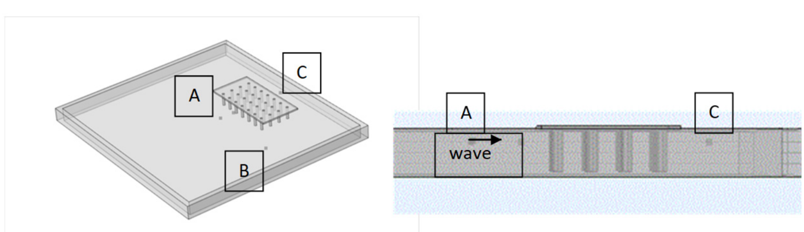

Fig. 2. Measurement points determined in simulation studies and location of wave source.

Looking at the band structure diagram shown in Figure 3, unfortunately, a complete band gap could not be obtained. However, it is seen that partial band gaps are obtained in the frequency regions of 25 Hz and higher.

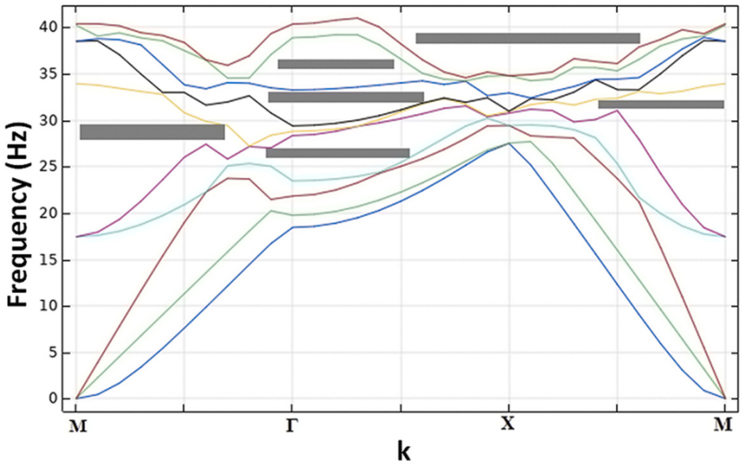

Fig. 3. Band structure obtained in simulation studies.

In addition, a striking element is that these band gaps are distributed in almost every direction. Based on this, it can be said that although it is not possible to dampen seismic effects in a full frequency range, there may be some damping in various frequency waves.

3 Results and discussions

In this section, based on the data obtained in the material and method section, the efficiency of the designed structure will be discussed by looking at the transmission losses and the progress of the waves in the time and frequency domain.

Considering the transmission losses shown in Figure 4, it is seen that in general, transmission losses occur at certain frequency points between 3Hz and 10Hz frequency value. Significant transmission losses occurring at local frequency values such as 3.5 Hz, 5.8 Hz, 8.3 Hz, 8.8 Hz, 9.3 Hz and 9.5 Hz are among the important outputs. Although there is no continuity in transmission losses in general, the restriction of transmission at point frequency values creates an opinion that the proposed structure can reduce seismic effects.

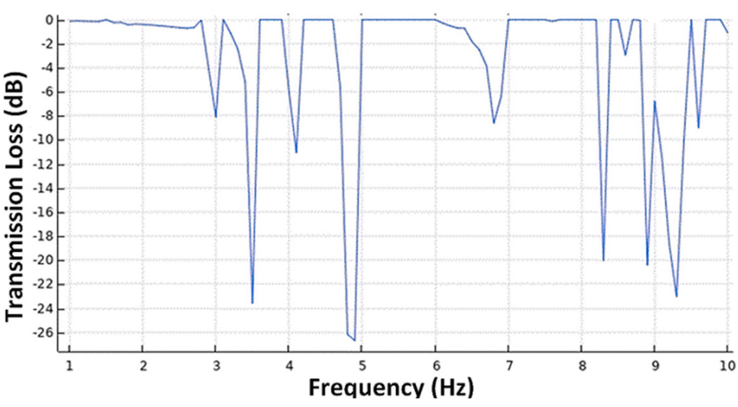

Fig. 4. Transmission losses between the proposed seismic metamaterials and the empty field.

 https://doi.org/10.1051/e3sconf/202340403003

However, the fact that the largest decibel losses occurred at 5.8 Hz is that wave propagation does not behave linearly with frequency. The region where transmission losses occur with more frequent intervals are between 8-10 Hz values. In this case, it creates the opinion that the proposed structure can function functionally in a narrow band such as 8-10 Hz, except for point values.

Looking at the results obtained in Figure 5, instantaneous emission amounts occurring at the frequency values specified in some time periods are given. Here, it is seen that the surface waves can pass behind the proposed structure in a very small amount, and seismic waves can be restricted to a significant extent in all the frequency values that occur in the transmission losses in general.

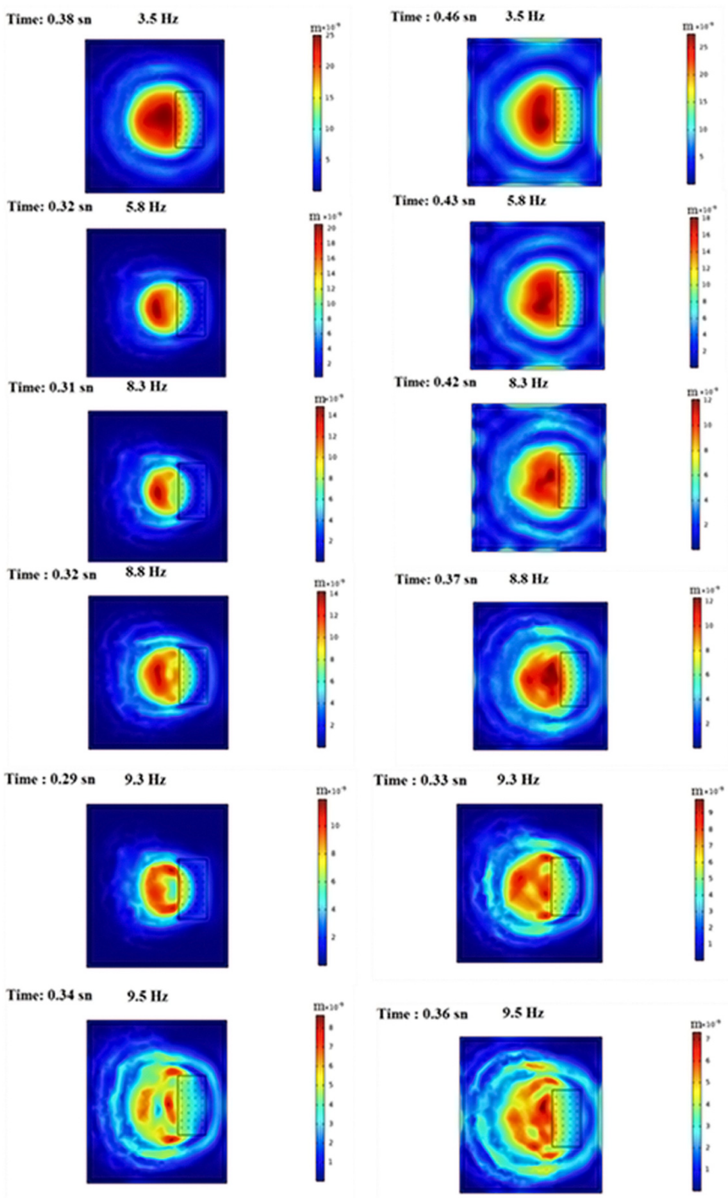

Fig. 5. Characteristic behaviour of wave propagation obtained as a result of simulation studies.

In general, as the frequency values increase, it is seen that the wave propagation increases more, however, the proposed structure, especially since the formation of the second order, cannot pass the waves. In general, it is seen that wave propagation increases significantly as time increases for all frequency values. However, remarkably, the fact that the wave motions in the proposed structure have been interrupted to a great extent regardless of the time parameter reveals that the proposed structure can be successful at these frequency values.

In addition, it is observed that as the frequency values increase, the wave propagation decreases. In this case, the results obtained especially at 9.5 Hz and 9.3 Hz values are able to absorb seismic effects at a good level. Finally, although wave propagation at 5.8 Hz was seen to be high, good seismic damping was achieved as indicated in transmission losses.

The similar characteristics of all results are generally seen as confirming each other in terms of simulation results. In addition, the fact that the wave propagation spreads linearly at each frequency value depending on the time proves that the proposed structure works reliably.

4 Conclusion

In general, the reusability of hazardous waste in metamaterial applications seems appropriate within the scope of the study. In addition, it can be a great advantage economically if waste is used as a replacement of conventional material.

In particular, millions of tons of waste are unrecoverable and trigger vital environmental problems. Instead of increasing carbon emissions by disposing of waste structures, it has been proven that these waste structures can be safely used in seismic metamaterials to reduce seismic effects.

Within the scope of the study, it has been shown that approximately 1.8 m3 of waste can be safely stored in an area of 90 m2. As a result, it is promising that both the mitigation of earthquake effects and the efficient implementation of waste recovery policies have been proven.

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 1919B022303039.

References

1. S. K. Duggal, Earthquake resistant design of structures, New Delhi: Oxford university press. (2007)
2. R. Bilham, Lessons from the Haiti earthquake, Nature, 463(7283), 878-879 (2010)
3. Y. Achaoui, T. Antonakakis, S. Brûlé, R. V. Craster, S. Enoch, & S. Guenneau, *Clamped seismic metamaterials: ultra-low frequency stop bands*, New Journal of Physics, 19(6), 063022 (2017)
4. Y. Achaoui, B. Ungureanu, S. Enoch, S. Brûlé, & S. Guenneau, *Seismic waves damping with arrays of inertial resonators*, Extreme Mechanics Letters, 8, 30-37 (2016)
5. R. Cai, Y. Jin, T. Rabczuk, X. Zhuang, & B. Djafari-Rouhani, *Propagation and attenuation of Rayleigh and pseudo surface waves in viscoelastic metamaterials*, Journal of Applied Physics, 129(12), 124903 (2021)

6. S. Kacin, M. Ozturk, U. K. Sevim, B. A. Mert, Z. Ozer, O. Akgol, & M. Karaaslan, *Seismic metamaterials for low-frequency mechanical wave attenuation*, Natural Hazards, 1-17 (2021)
7. A. A. Zadpoor, *Mechanical meta-materials*, Materials Horizons, 3(5), 371-381 (2016)
8. C. Z. Fan, Y. Gao, & J. P. Huang, *Shaped graded materials with an apparent negative thermal conductivity*, Applied Physics Letters, 92(25), 251907 (2008)
9. B. F. Spencer Jr, & S. Nagarajaiah, *State of the art of structural control*, Journal of structural engineering, 129(7), 845-856 (2003)
10. R. Xu, M. Muzamil, L. Fan, K. Yuan, H. Yang, & Q. Du, *Broadband seismic metamaterial with an improved cylinder by introducing plus-shaped structure*, EPL (Europhysics Letters), 133(3), 37001 (2021)
11. F. Basone, O. S. Bursi, F. Aloschi, & G. Fischbach, *Vibration mitigation of an MDoF system subjected to stochastic loading by means of hysteretic nonlinear locally resonant metamaterials*, Scientific Reports, 11(1), 1-15 (2021)
12. H. J. Xiang, Z. F. Shi, S. J. Wang, & Y. L. Mo, *Periodic materials-based vibration attenuation in layered foundations: experimental validation*, Smart Materials and Structures, 21(11), 112003 (2012)
13. T. V. Varma, B. Ungureanu, S. Sarkar, R. Craster, S. Guenneau, & S. Brûlé, *The influence of structure geometry and material on seismic metamaterial performance*, arXiv preprint arXiv:2007.14424 (2020)
14. B. Ungureanu, Y. Achaoui, S. Brule, S. Enoch, R. Craster, & S. Guenneau, *Seismic wave shield using cubic arrays of split-ball resonators*, arXiv preprint arXiv:1904.10767 (2019)
15. M. M. Hajjaj, & J. Tu, *A seismic metamaterial concept with very short resonators using depleted uranium*, Archive of Applied Mechanics, 1-22 (2021)
16. S. Dharmaraj, V. Ashokkumar, R. Pandiyan, H. S. H. Munawaroh, K. W. Chew, W. H. Chen, & C. Ngamcharussrivichai, *Pyrolysis: An effective technique for degradation of COVID-19 medical wastes*, Chemosphere, 275, 130092 (2021)
17. M. Aggarwal, *Pollution watchdog releases guidelines to handle COVID-19 biomedical waste*, Retrieved June, 30, 2020 (2020)
18. H. B. Sharma, K. R. Vanapalli, V. S. Cheela, V. P. Ranjan, A. K. Jaglan, B. Dubey, & J. Bhattacharya, *Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic*, Resources, conservation and recycling, 162, 105052 (2020)
19. S. Jung, S. Lee, X. Dou, & E. E. Kwon, *Valorization of disposable COVID-19 mask through the thermo-chemical process*, Chemical Engineering Journal, 405, 126658 (2021)
20. M. Miniaci, A. Krushynska, F. Bosia, & N. M. Pugno, *Large scale mechanical metamaterials as seismic shields*, New Journal of Physics, 18(8), 083041 (2016)
21. H. T. Özkahraman, & M. Şirin, *Göltaş Kireçtaşının Kayaç Kalitesi ve Öğürülebilirliğinin Tespiti*, Geosound, Number: 33, pp. 155-162 (1998)
22. M. Abu-Saleem, Y. Zhuge, R. Hassanli, M. Ellis, M. Rahman, & P. Levett, *Evaluation of concrete performance with different types of recycled plastic waste for kerb application*, Construction and Building Materials, 293, 123477 (2021)
23. H. Binici, M. H. Alma, R. Gemci, & M. Y. Durgun, *Atık Polietilen (PE) bardaklardan üretilen çimentosuz harçların fiziksel ve mekanik özellikleri*, Yapı Teknolojileri Elektronik Dergisi, 7(1), 71-79 (2011)

24. A. V. C. I. Ahmet, & Ö. F. Erkendirci, *Farkli Çatlak Açilarina Sahip Çelik Tel Takviyeli Polietilen Kompozitlerin Yorulma Yükü Altinda Kirilma Davranışlarının İncelenmesi*, Prooceedings of 8th International Fracture Conference (2007)