Performance of Sand–Rubber Mixture Infill Trench for Ground Vibration Screening

J. S. Dhanya, A. Boominathan, and Subhadeep Banerjee

Abstract Ground vibrations arising from construction and industrial activities and road/rail traffic can induce settlement issues, cracks, and severe damage to adjacent and remote structures. One of the well-established methods to eliminate such unwanted ground-borne vibrations is to incorporate trench barriers between the source of vibration and the structure to be protected. Recently, the use of shredded rubber from recycled tires has gained prominence in various geotechnical applications. The high energy absorption capacity of rubber is well established in the past, making it an ideal material in vibration mitigation studies. In the present study, 2D finite element analysis was carried out to investigate the use of sand–rubber tire mixture (SRM) infill trench barriers for the screening of ground-borne vibration due to vertical ground vibrations. In the present study, the typical soil profile from the Indo-Gangetic plain region is considered. 1 m width open and SRM infill trenches with a depth of 1–3 m are considered. The rubber content in the SRM fill trenches was chosen as 30% and 50%. The hyper elastic material model was adopted for the modeling of the SRM infill trench, while the soil medium was modeled using the hypoelastic constitutive model. The ground excitation was created by applying sinusoidal vertical motion with 2 m/s amplitude and a frequency of 50 Hz at the ground surface away from the trench. During the excitation, the vibration levels were computed at different locations in front of and away from the trenches. It was found that SRM infill trench with 50% rubber content performs similar to the open trenches to reduce the vertical vibration amplitude.

Keywords Vibration mitigation · Infill trench · Sand–rubber mixture · FEM

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1 Introduction

Ground-borne vibrations arising from construction activities such as blasting, demolition of buildings, dynamic compaction, excavation, and driving of piles very closer to civil engineering structures often get transmitted to nearby buildings. Besides, road/rail traffic, machine induced vibrations, and other industrial activities can damage the neighboring buildings, streets, underground pipelines, and as well as on sensitive equipment and cause disturbance to the occupants of the buildings. In severe cases, ground-borne vibrations can cause soil settlement and soil densification leading to damage to the surrounding structures. The adverse effects of dynamic impact loading, such as pile driving, even lead to shaking of structures, settlement due to liquefaction, and the formation of localized heave. The structural damage can be chiefly attributed to vibratory cracking from ground vibrations, resonant structure vibrations, and vibratory settlement of foundation [1]. It is essential to estimate the transmitted vibration intensity to avoid structural damage, which depends on the attenuation characteristics of the soil that act as the transmitting medium. To achieve the levels of ground vibration specified in the standard and to minimize the unwanted ground-borne vibrations for reducing structural damage and improving building functionality, vibration control through cost-effective vibration screening methods is essential.

Wave barriers such as trenches can be used as a successful technique to minimize the problems due to ground vibrations. The trench barriers are installed between the source of vibration and the structure to be protected. The problem of screening of vibrations by the use of trench barriers can be collectively classified into active isolation and passive isolation. Active isolation involves the installation of wave barriers close or near to the vibration source to reduce the propagation of waves away from the source. In contrast, passive isolation involves providing wave barriers near the structure where the impact caused by the vibration should be reduced [1, 2]. Such trenches on the path of wave propagation typically attenuate the surface waves, thereby reducing the intensity of the ground vibration.

The most efficient wave barriers to screen ground vibration are open trenches. The introduction of open trenches poses several limitations for practical applications. Due to the localized collapse of the trench walls, safety issues, and unexpected filling owing to rain or construction activities, it is often difficult to install and maintain open trenches to the desired depth and width. Baker [3] has conducted a series of field model tests to investigate the effectiveness of barriers infilled with bentonite (i.e., soft barrier) and concrete (i.e., stiff barrier) installed near and far from the source of the disturbance. Later, infilled trenches with geofoam, sawdust, and bentonite were widely investigated [4, 5].

Several experimental studies were conducted to examine the key parameters influencing the efficiency of wave barriers in vibration isolation, which suggested that the depth of the trench and the wavelength of Rayleigh waves have a significant impact on vibration screening [2]. Woods [1] reported that a minimum depth of 0.6 times

Rayleigh wavelength should be provided for effective isolation. It was reported that the width of the trench has little effect on vibration screening.

Lately, rubber was used to a large degree as an anti-vibration product to limit noise, shock, and vibration isolation in a wide variety of industries. One of the main applications of scrap tire with rubber as its principal component is its utility in vibration isolation due to high damping and energy absorption capacity [6, 7]. The scrap tire products such as tire shreds, chips, and aggregates have found its way into the civil engineering field since the 1990s. By and large, the unrecycled scarp tire known as 'black pollutant' [8] posing global pollution due to its sheer volume was found to be an excellent additive to soil mainly due to its non-biodegradability. In the geotechnical field, the tire-derived geomaterials have witnessed rapid growth in applications such as lightweight landfills, backfilling of retaining walls and buried pipeline, and ground improvement material for highway embankments [9, 10]. The use of tire-derived geomaterials mixed with sand for earthquake protection of buildings has been the topic of interest in recent years [11–13]. The liquefaction mitigation potential of tire chips mixed with soil for foundation soil and as backfill material was explored by recent studies [14, 15]. The high damping characteristics of scrap tires mixed with sand point out its promising potential in vibration mitigation.

Recently, a few studies have investigated the use of sand–rubber mixture (SRM) as a wave barrier. Mahdavisefat et al. [16] conducted a series of full-scale field experiments to investigate the effect of open and infilled trenches on vibration screening. The authors proposed that sand–rubber mixture can be used to fill the trench as it is a lightweight, high energy absorbing and environmentally friendly material for a wide range of vibration frequencies (10–600 Hz). It was also reported that the SRM with 30% rubber content performed better than other mixtures. Chew and Leong [17] conducted a full-scale field experimental study to investigate the performance of sand–rubber mixture as a vibration barrier, and it was found that the infilled trench with high rubber content significantly mitigates the vibration and suggested that optimum depth of SRM infill trench was similar to the findings of Woods [1].

Limited studies reported on SRM in fill trench barriers arrived at different optimum proportions of SRM for vibration isolation. In view of this, the present study aims to investigate the effectiveness of sand–rubber tire mixture (SRM) as the fill material for the infill trench barrier for the screening of ground-borne vibration by carrying out numerical analysis using FE Code ABAQUS.

2 SRM for Vibration Mitigation

2.1 Problem Statement

The present study focuses on the performance of an innovative screening technique using SRM infill trench barrier for ground-borne vibration mitigation. Numerical analysis was carried out on a FE model of the trench barrier underlain by a layered

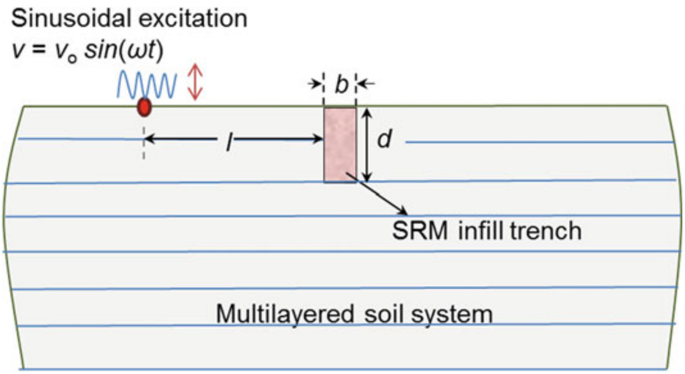

Fig. 1 SRM-isolation system used for vibration mitigation

soil medium. Figure 1 shows the schematic representation of the trench barrier with width w and depth d.

The vertical sinusoidal loading in terms of velocity, $v(t) = v0\sin(\omega t)$, was applied at the ground surface at a distance of l from the trench. Ground vibrations generated due to the vertical excitation were obtained at a fixed distance on either side of the wave barrier.

The active vibration screening efficiency of the SRM infilled trench barrier was quantified in terms of amplitude reduction factor (ARF) i.e., ratio of velocity amplitude after and before the installation of the trench at different locations caused by the harmonic excitation.

2.2 *Finite Element Modeling*

A 2D numerical study was carried out on the trench barrier system with SRM fill material for vibration mitigation using ABAQUS (Fig. 2.). The width (b) of the trench

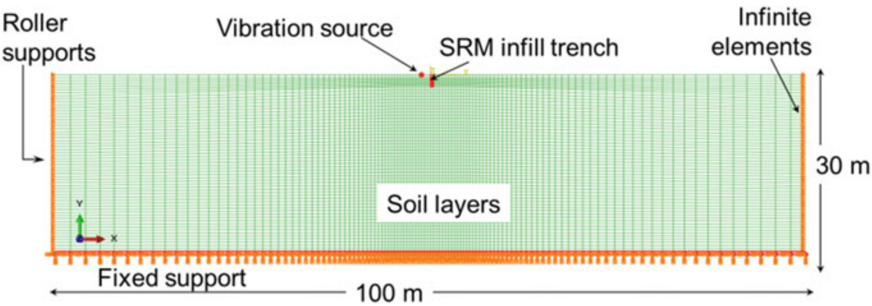

Fig. 2 Finite element model of the SRM isolation system

was considered as 1 m, while the depth of the trench (d) was varied from 1 to 3 m. The source to barrier distance was kept constant at 6 m. The entire trench system was underlain by a 30 m deep layered soil medium corresponding to a typical soil profile from the Indo-Gangetic plain region reported in Dhanya et al. [13]. The shear wave velocity of the top layer of soil was 200 m/s, and the Rayleigh wave velocity was estimated to be 187 m/s. The length of the soil medium is considered as 100 m to ensure free-field conditions. In the numerical analysis, the rubber content of SRM infill trench was considered as 30 and 50%.

The maximum mesh size for the problem was determined using CFL criteria [18], considering the wavelength of the vibrations and the shear wave velocity of the soil medium to ensure accurate wave propagation. The soil medium and the trench were discretized using four-node plane strain continuum elements. The mesh size of the soil medium was varied from 1 m × 1 m at the center to 5 m × 1 m toward the edges of the model. The default boundary conditions were used to represent the soil matrix, while infinite elements were provided at the far-field to ensure the absorption of outgoing waves, thereby preventing wave reflection.

The hyperelastic material model was adopted for the modeling of the SRM infill trench layer. The soil medium was assumed as homogeneous and the hypoelastic constitutive model was adopted to model the soil. The details of the material properties for the soil medium, sand, and SRM in terms of shear modulus degradation curves, stress–strain curves for SRM, Poisson's ratio, and density, were adopted from Dhanya et al. [13]. The Rayleigh damping coefficients method was adopted to account for the damping of vibrations in the material.

In the present study, vertical sinusoidal ground vibration of amplitude 2 m/s with frequency of 50 Hz was applied at the ground surface (Fig. 1). During the excitation, the time history of velocity before and after the trench and at different points of interest was obtained.

2.3 Results and Discussion

The velocity response measured just after the trench barrier with a depth of 1.5 m (SRM with 30% rubber content) for the sinusoidal vertical excitation on the ground surface is presented in Fig. 3. It can be easily noticed from the figure that the reduction in velocity amplitude is more significant due to the introduction of the open trench which is well established in past studies [1, 19, 20].

The efficiency of vibration screening using trenches was analyzed in terms of amplitude reduction factor (ARF), i.e., the ratio of the amplitude of vibration after and before the installation of trench barriers. Figure 4 presents the variation of ARF with the depth of trench normalized with the Rayleigh wavelength (d/λ). It can be noted that as the depth of trench increases, there is a general trend of reduction in ARF for open and SRM infill trench cases. The ARF of 0.3 was achieved between d/λ of 0.6 to 0.8, similar to the findings of Woods [1] in all three cases. The SRM50 infill trench was able to achieve 0.85 times ARF as that of the open trench, while SRM

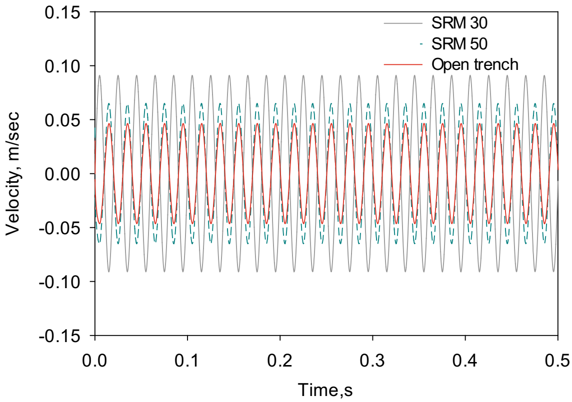

Fig. 3 Velocity–time histories after the trench barrier at $l = 1$ m and excitation frequency = 50 Hz

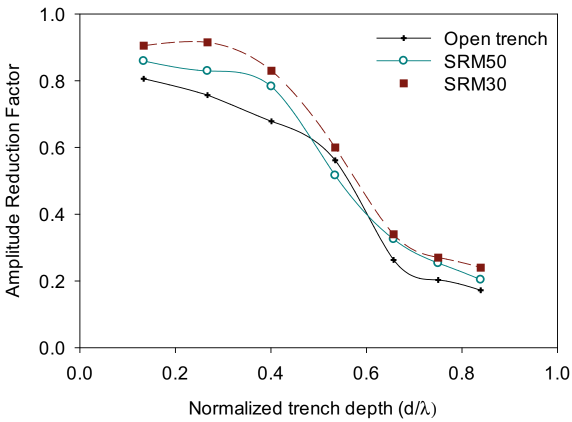

Fig. 4 Variation of amplitude reduction factor with depth of the trench ($l = 2$ m)

30 infill trench was able to reach around 0.7 times ARF as that of the open trench. Therefore, SRM infill trench with the rubber content of 50% screen the vibration amplitude by only about 15% less than that for open trenches.

Figure 5 presents the variation of ARF at varying distance from the source of vibration excitation. The sudden reduction in ARF with introduction of trench at a distance of 2 m from the source of excitation is evident for all the three cases followed by a gradual reduction of ARF. ARF of 0.3 was achieved at a distance of 1 m away from the open trench, while for SRM50 and SRM 30 trenches, it was achieved at a distance of 1.2 and 2 m, respectively, away from the trench location. At a distance of 2 m away from the trench the vibration reduction due to SRM 50 is 20% less than that of open trench while vibration reduction due to SRM 50 is 30% less than that of open trench. The SRM50–filled trench was found to provide best barrier effects than

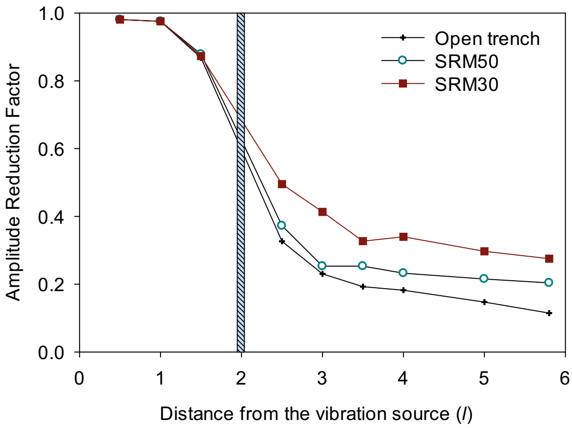

Fig. 5 Variation of amplitude reduction factor with distance from the trench (Depth = 2 m)

SRM 30 and exhibits comparable efficiency to that of open trench. Similar trends were also observed by Chew and Leong [17].

3 Conclusions

In the present paper, finite element studies were carried out to evaluate the effectiveness of SRM infill trenches to mitigate the ground-borne vibrations. Overall, it was found that the introduction of SRM infill trench barriers can significantly reduce the intensity of vertical ground vibrations. SRM infill trench with the rubber content of 50% screen the vibration amplitude by only about 15% less than that for open trenches, and hence, it can be used for screening of high frequency vibrations. However, further studies are required to arrive optimum dimensions of SRM infill trenches for effective screening of ground vibrations at wide range of frequency of excitation under different ground conditions.

References

1. Woods, R.D.: Screening of surface waves in soil. J. Soil Mech. Found. Eng. **94**(SM4), 951–979 (1968)
2. Richart, F.E., Hall, J.R., Woods, R.D.: Vibrations of Soils and Foundations, Englewood Cliffs. Prentice-Hall, NJ (1970)
3. Baker, J.M.: An experimental study on vibration screening by in-filled trench barriers, M.Sc. Thesis, State University of New York at Buffalo, USA (1994)
4. Murillo, C., Thorel, L., Caicedo, B.: Ground vibration isolation with geofoam barriers: centrifuge modeling. Geotext. Geomembr. **27**, 423–434 (2009)

5. Celebi, E., Firat, S., Beyhan, G., Cankaya, I., Vural, I., Kirtel, O.: Field experiment on wave propagation and vibration isolation by using wave barriers. Soil Dyn Earthq. Eng. **29**(5), 824–833 (2009)
6. Hazarika, H., Yasuhara, K., Karmokar, A. K., Mitarai, Y.: Shaking table test on liquefaction prevention using tire chips and sand mixture. In: Proceedings of the International Workshop on Scrap Tire Derived Geomaterials—Opportunities and Challenges, IW-TDGM 2007; pp. 215–222 (2008)
7. Kaneko, T., Orense, R.P., Hyodo, M., Yoshimoto, N.: Seismic response characteristics of saturated sand deposits mixed with tire chips. J. Geotech. Geoenviron Eng. **139**(4), 633–643 (2013)
8. Xiong, W., Li, Y.: Seismic isolation using granulated tire–soil mixtures for less-developed regions: experimental validation. Earthq. Eng. Struct. Dynam. **42**, 2187–2193 (2013)
9. Edil, T., Bosscher, P.: Engineering properties of tire chips and soil mixtures. Geotech. Test. J. **17**(4), 453 (1994)
10. Hazarika, H., Yasuhara, K., Kikuchi, Y., Karmokar, A.K., Mitarai, Y.: Multifaceted potentials of tire-derived three-dimensional geosynthetics in geotechnical applications and their evaluation. Geotext. Geomembr. **28**(3), 303–315 (2010)
11. Tsang, H., Lo, S.H., Xu, X., Sheikh, M.N.: Seismic isolation for low-to-medium-rise buildings using granulated rubber–soil mixtures: numerical study. Earthq. Eng. Struct. Dynam. **41**, 2009–2024 (2012)
12. Dhanya, J.S., Boominathan, A., Banerjee, S.: Performance of geo-base isolation system with geogrid reinforcement. Int. J. Geomech. **19**(7), 1–13 (2019)
13. Dhanya, J.S., Boominathan, A., Banerjee, S.: Response of low-rise building with geotechnical seismic isolation system. Soil Dyn. Earthq. Eng. **136**, 106187 (2020)
14. Hazarika, H., Kohama, E., Sugano, T.: Underwater shaking table tests on waterfront structures protected with tire chips cushion. J. Geotech. GeoEnviron. Engg., ASCE, **134**(12), 1706–1719 (2008)
15. Hazarika, H., Pasha, S.M.K., Ishibashi, I., Yoshimoto, N., Kinoshita, T., Endo, S., Karmokar, A.K., Hitosugi, T.: Tire chips reinforced foundation as liquefaction countermeasure for residential buildings. Soils and Founds **60**(2), 315–326 (2020)
16. Mahdavisefat, E., Salehzadeh, H., Heshmati, A.A.: Full-scale experimental study on screening effectiveness of SRM infilled trench barriers. Geotechnique **68**(10), 869–882 (2018)
17. Chew, J.H., Leong, E.C.: Field and numerical modelling of sand-rubber mixtures vibration barrier. Soil Dynam. Earthq. Eng. **125**, 105740 (2019)
18. Courant, R., Friedrichs, K., Lewy, H.: On the partial difference equations of mathematical physics. IBM J Res Dev **11**(2), 215–234 (1967)
19. Dasgupta, B., Beskos, D.E., Vardoulakis, I.G.: Vibration isolation using open or filled trenches Part 2: 3-D homogeneous soil. Comput. Mech. **6**, 129–142 (1990)
20. Saikia, A., Das, U.K.: Analysis and design of open trench barriers in screening steady-state surface vibrations. Earthq. Eng. Eng. Vib. **13** (2014)