Use of Sand-Rubber Mixture (SRM)-Filled Trenches for Pile Driving Induced Vibration Screening

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Abstract. Pile driving induced vibrations creates a huge concern for the construction industry since it may cause damage to the surrounding structures or settlement of the soil, depending on the intensity of ground shaking or vibration. It is essential to estimate the transmitted vibration intensity to avoid structural damages, which are highly dependent on the physical properties of the pile and the soil that acts as the transmitting medium. One widely adopted solution for the screening of pile-driving induced ground vibration is the use of infill trench in the path of wave propagation. The high damping and energy absorption capacity of rubber is well established in the past, making it an ideal material in vibration mitigation studies. In this paper, the use of sand-rubber mixture (SRM) as a trench infill material has been investigated to understand its effect on reducing the response of impact pile induced vibrations to adjacent structures. The SRM-filled trench barrier was provided as a passive isolation system, and field tests were conducted to evaluate its vibration screening performance under impact loading due to piling. The outputs from the analysis, in the form of acceleration-time history and Peak Particle Velocity (PPV), was obtained on either side of the trench with and without SRM infill. Overall, SRM was found to have a better performance with regards to the attenuation of surface waves. Further, a considerable reduction in peak acceleration and PPV was noted due to the introduction of SRM-filled trench barriers.

Keywords: Infill trench · Pile driving · Sand-rubber mixture

1 Introduction

Ground vibrations generated from construction activities such as pile driving has increasingly become a major concern for the strength and serviceability of adjacent structures and underground utilities. In highly populated cities, the adverse effects of such vibrations involve severe damage to nearby buildings, discomfort to the occupants, and affecting the functionality of sensitive equipment like electron microscopes (Head and Jardine 1992). The intensity of shaking during driving piles into the ground is more or less severe, depending on the way the pile is inserted into the ground, physical properties of the pile and the surrounding soil conditions. The structural damage to the nearby buildings usually arises from building shaking due to transient

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vibrations, soil settlement from densification, and liquefaction (Long 1989). Though few cases of direct damage to structures when the distance from the pile is greater than the pile length has been reported, settlement damage to the surface and buried structures are evident up to a distance of 400 m from the pile driving location (Wiss 1967).

Pile installation for impact pile driving creates a high intensity of shaking due to large strain dynamic stress conditions, high soil resistance involved. For impact driven piles, at the tip of the pile, each impact causes a volume displacement, which results in both primary waves (P-wave) and shear waves (S-wave) traveling outward from the cavity as spherical wavefronts. The P-wave and S-waves, while encountering the surface of the ground, part of their energy is converted to surface waves (R-wave), and part is reflected into the ground as P and S waves transmitting energy to the ground surrounding a pile. The reflected waves are potentially damaging to neighboring structures (Woods and Sharma 2004).

To achieve the limits of ground vibration specified in building standards, effective and efficient methods of screening the ground vibration is a growing concern. Often, due to the limited availability of suitable vibration mitigation measures, alternative foundation methods, or imposing restrictions on pile driving are pursued. Though ground vibrations can be reduced by decreasing dynamic loads from the construction source, such precautions may not be practical in most cases.

A highly recommended vibration mitigation method is the implementation of a wave barrier in the path of wave propagation. Typically, wave barriers such as open trenches and in-filled trenches are commonly adopted for vibration screening. The principle of working of a trench is to reflect the waves towards the source or to absorb the wave energy, hence preventing the waves from propagating beyond the trench towards a vulnerable structure or location (Alzawi and El Naggar 2011). Though open trenches are considered as the most efficient wave barriers for ground vibration mitigation, they pose several limitations such as difficulty in installation and maintenance, safety issues, and environmental problems due to accidental filling of trenches by rain or other activities. The use of in-filled trenches is found effective in terms of stability, safety, and as a permanent protection barrier (Ulgen and Toygar 2015).

Recently, the use of shredded rubber from recycled tires has gained prominence in geotechnical engineering as lightweight fills, backfills, and highway embankments (Humphrey and Manion 1992; Rowe and McIsaac 2005). The high damping and energy absorption capacity of rubber is well established in the past, making it an ideal material in vibration mitigation studies (Hazarika et al. 2008; Kaneko et al. 2013). The recycled tyres in the form of rubber chips, crumb rubber, and shredded rubber mixed with sand are recently adopted in vibration isolation studies for earthquake protection of buildings in recent years (Tsang et al. 2012). Sand-Rubber Mixtures (SRM) are found to have low dry density, stiffness, shear modulus, and high damping ratio (Senetakis et al. 2009). Few studies were carried out on the applicability of SRM-filled trenches for the mitigation of ground-borne vibrations (Chew and Leong 2019). However, limited field investigations are available exploring the performance of the SRM-filled trench system for the reduction of pile-driving induced vibration. In view of this, the present study explores the behavior and effectiveness of SRM as fill material for trench on reducing the response of impact pile induced vibrations to adjacent structures in the horizontal direction using field investigation.

2 Field Study

A full-scale field test was carried out to measure the vibrations during the installation of a driven cast in situ pile. The test involves measurement of ground vibrations during pile driving operation considering SRM-filled trench placed at a fixed distance from the pile foundation as a wave barrier, as shown in Fig. 1. Vibration measurements were undertaken to study the effect of without trench, open trench, and SRM-filled trench during the pile driving operation and the corresponding attenuation of ground vibrations using open, and SRM-filled wave barriers were studied.

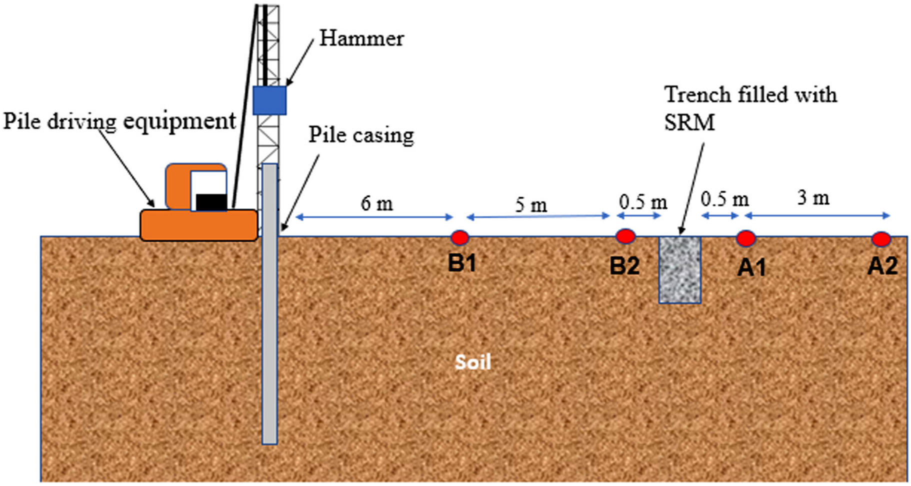


Fig. 1. Schematic of the pile foundation installation and SRM-filled trench

2.1 Site Description and Piling Details

The test site (Fig. 2a) is a flat construction area located 20 km north of Chennai, India. Soil investigation, including boreholes and standard penetration tests (SPT), was conducted at the site, based on which the entire area was considered as a three-layer system. The top layer consists of 3 m to 4 m thick soft clay followed by loose to medium dense sand layer up to a depth of 19 m. The bottom-most layer below 19 m from the surface consists of very dense sandy strata with SPT-N value above 100.

Since the soil profile is predominantly sand, it was decided to install cast-in-situ concrete piles with 450 mm diameter to support the proposed multistorey buildings. For the installation of the prototype pile of 450 mm diameter at the test site, a mild steel pipe casing was driven using an impact hammer of weight 4.1 tonnes with an average height of drop of 1.5 m (Fig. 2b), up to a depth of 20 m below the ground level. Three test piles separated by a distance of 0.7 m are considered in the present study.

(a) (b)

Fig. 2. Photograph of (a) piling site, and (b) test pile driving

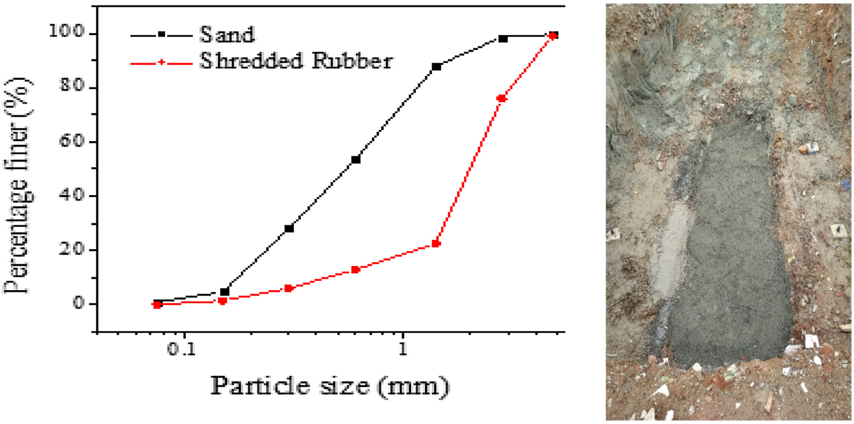
2.2 In-Filled Trench with Sand Rubber Mixtures

The rubber shreds used for the SRM were obtained from the recycled tyre from the local market and grounded into smaller granules. The specific gravities of the sand and shredded rubber are 2.67 and 1.12, respectively. The grain size distribution of shredded rubber and sand are shown in Fig. 3a. The sand used for the study is classified as well-graded sand, and the rubber shreds were classified as similar to poorly graded sand as per IS 1498:1970 for the present study. For the field study, SRM with 30% rubber content by weight was considered. The preweighed quantities of sand and rubber are uniformly mixed in the site before placing it in the trench. A relative density of about 65% was maintained throughout the test.

A rectangular trench of 3 m length, 1 m width, and 2 m depth was excavated using a digger/excavator at a distance of 11.5 m away from the pile foundation. The trench was then filled with SRM for the desired rubber content and relative density. Fig. 3b shows the trench filled with SRM in the site for the present study.

2.3 Vibration Monitoring

Vibration measurement was carried out separately during the driving of three test piles located in the same row. During the driving of the first test pile, the trench was not constructed at the site; during driving of the second test pile open trench was constructed and during the driving of third test pile in-filled trench with SRM was constructed. The ground-borne vibrations during pile driving were measured with the help of four piezoelectric type accelerometers fixed in the vertical direction. Among two accelerometers fixed before the trench, one is fixed at a distance of 6 m from the source and another one at a distance of 11 m from the source (at a distance 0.5 m from the trench), as shown in Fig. 1. After the trench, one is fixed at a distance of 0.5 m away from the trench and another one at a distance of 3.5 m from the trench. The accelerometers were connected to a Data Acquisition system consisting of HBM make multi-channel digital carrier frequency amplifier system (model: QuantumX –



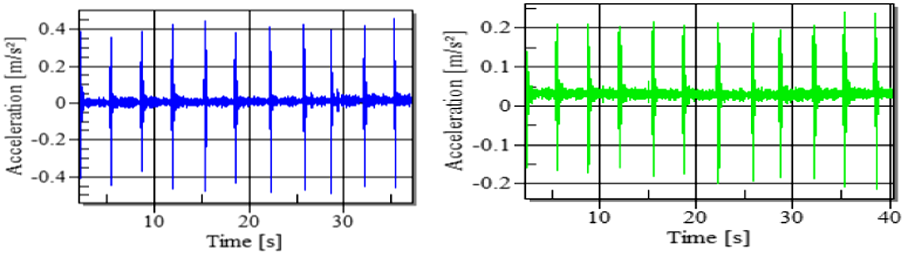
(a) (b)

Fig. 3. (a) Grain size distribution curve for sand and shredded rubber (b) Trench with SRM fill

MX1615BR) and CatmanEasy V4.1.2 software installed on a Laptop to monitor and record the wave traces.

2.4 Results and Discussion

The typical waveform of time history acceleration recorded at a distance of 0.5 m before and after the open trench during pile driving operation is presented in Fig. 4. The continuous impact from the hammer during the pile driving operation is represented by the peaks in the acceleration-time history plot (Fig. 4).



(a) (b)

Fig. 4. Typical time history of acceleration recorded at a distance of 0.5 m before (a), and after open trench (b) during piling at a depth of 6 m to 7 m.

The recorded time history of acceleration is corrected for baseline, and the ambient noise is filtered by the Butterworth bandpass filter using Seismosignal 2020 software. The corrected time history of the typical acceleration for a single hammer impact at a distance of 13 m from the pile for cases of without trench and SRM-filled trench (at a distance of 0.5 m from the trench) during piling at a depth of 8 m to 9 m is shown in

Fig. 5. It can be noticed from Fig. 5 that compared to the without trench case, there is a significant reduction in peak acceleration for the SRM-filled trench case.

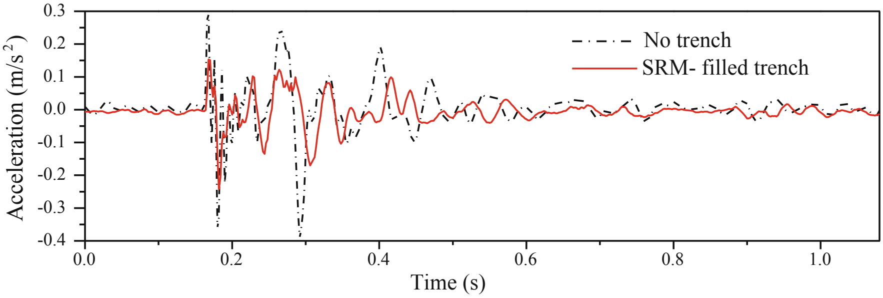


Fig. 5. Typical time history of acceleration recorded at a distance of 0.5 m after trench (at point A1) for the without trench and SRM-filled trench (piling at a depth of 8 m to 9 m)

Table 1 shows the peak vertical acceleration obtained during pile driving operations for the case without trench, open trench, and SRM-filled trench at a distance of 0.5 m before and after the trench. A maximum reduction in peak acceleration of 60% was observed for the open trench, while for SRM-filled trench, a maximum reduction of 44% was observed. It was found that the peak vertical acceleration values after the open trench varies from 0.92 m/s^2 to 3.54 m/s^2, i.e., comparatively low value of acceleration at softer layers of soil.

Table 1. Peak vertical acceleration

Test pile No	Type of trenches	Peak vertical acceleration, m/s^2	
		Before trench (point B2)	After trench (point A1)
1	Without trench	0.891	0.715
2	Open trench	0.712	0.38
3	SRM-infill	1.083	0.723

The peak particle velocity (PPV) is a measure of the damage potential of vibration, and it is used for building safety measures. Hence the time history of velocity is computed from the measured time history of acceleration using Seismosignal 2020 software. Figure 6 shows the variation in PPV with distance away from the trench location for a pile penetration depth of 15 m. The decay of PPV with distance is evident from the figure. The open trench was found to achieve the maximum screening, followed by the SRM-filled trench. The maximum peak particle velocity (PPV) obtained from the time history of acceleration during piling driving operations are presented in Table 2. It can be seen from Table 2 that the peak particle velocity is considerably reduced after the trench. It is observed that the open trench barrier shows better performance followed by the SRM-filled trench. The PPV values show a reduction of 46% for open trench and 37% for SRM-filled trench compared to without trench case. Similar trends were also reported by Chew and Leong (2019) for field vibration studies using SRM-filled trenches. It is observed that at a stronger soil layer, the velocity of vibration is more compared to the other depth owing to the increase in energy transferred. Slight variation in the PPV and PA values before the trench for different cases can be attributed to the fact that for each case, the considered pile location is marginally different.

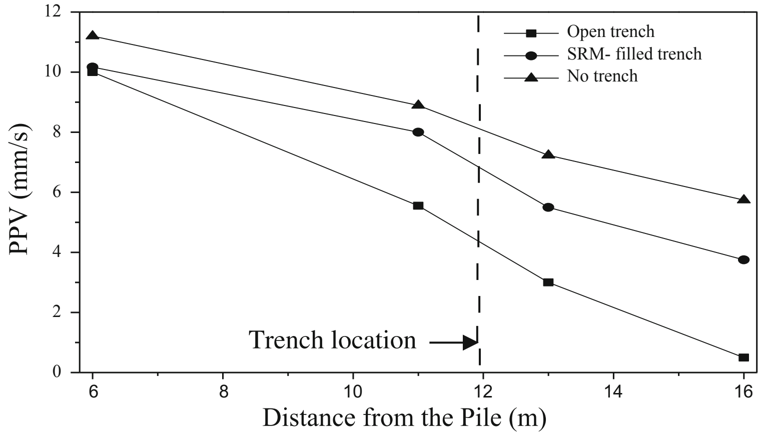


Fig. 6. The variation in PPV with distance away from the trench location for a pile penetration depth of 15 m

Table 2. Maximum peak particle velocity

Test pile no	Type of trenches	Maximum PPV, mm/s		Percentage reduction, %
		Before trench (point B2)	After trench (point A1)	
1	Without trench	8.89	7.23	19
2	Open trench	5.55	3	46
3	SRM-infill	8	5.05	37

3 Conclusions

In the present paper, a full-scale field experimental study was carried out to evaluate the effectiveness of open and infill trenches to mitigate the ground-borne vibrations due to impact pile driving. It is found that SRM-filled trenches even with 2 m depth can reduce the PPV by about 37% indicating the efficiency of the SRM -filled trenches in the screening of ground-borne vibration due to the pile driving.

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