

Sand-rubber mixtures as vibration dampening foundation materials: scaled physical model studies

Mélanges de sable et de caoutchouc comme matériaux de fondation amortissant les vibrations: études sur modèles physiques à l'échelle

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ABSTRACT: The accumulation of scrap rubber tires is a serious environmental issue. Rubber is a good damping material. In view of these, it is prudent to use rubber along with soil for engineering applications in general and possibly as foundation materials in particular. In this regard, some past studies have discretely evaluated the physical and mechanical properties of soil-rubber mixtures. However, there is a lack of comprehensive experimental studies highlighting the significance of the use of sand-rubber mixtures as vibration dampening foundation materials. The present study deals with the instrumented laboratory scaled physical models subjected to a series of impact hammer tests. Different base conditions for the physical models consisting of fixed base, and structure founded on sand-rubber mixture layer in a tank filled with sand are considered. The impact force and the acceleration responses of the structure are recorded using an HBM made amplifier with the data acquisition system. The damping ratio values are estimated from the frequency response function plots of the measured signals. The results of the present study show that the sand-rubber mixtures possess an adequate potential for their application as vibration dampening foundation materials for low-rise buildings.

RÉSUMÉ: L'accumulation de pneus usés en caoutchouc constitue un grave problème environnemental. Le caoutchouc est un bon matériau amortisseur. Compte tenu de cela, il est prudent d'utiliser le caoutchouc avec la terre pour des applications techniques en général et éventuellement comme matériaux de fondation en particulier. À cet égard, certaines études antérieures ont évalué discrètement les propriétés physiques et mécaniques des mélanges sol-caoutchouc. Cependant, il manque des études expérimentales complètes mettant en évidence l'importance de l'utilisation de mélanges sable-caoutchouc comme matériaux de fondation amortisseurs de vibrations. La présente étude porte sur des modèles physiques instrumentés à l'échelle d'un laboratoire soumis à une série d'essais au marteau. Différentes conditions de base pour les modèles physiques constitués d'une base fixe et d'une structure fondée sur une couche de mélange sable-caoutchouc dans un réservoir rempli de sable sont prises en compte. La force d'impact et les réponses d'accélération de la structure sont enregistrées à l'aide d'un amplificateur fabriqué par HBM avec le système d'acquisition de données. Les valeurs du rapport d'amortissement sont estimées à partir des tracés de fonction de réponse en fréquence des signaux mesurés. Les résultats de la présente étude montrent que les mélanges sable-caoutchouc possèdent un potentiel adéquat pour leur application comme matériaux de fondation amortisseurs de vibrations pour les bâtiments de faible hauteur.

Keywords: Sand rubber mixtures; damping; foundation; scaled physical models.

1 INTRODUCTION

The accumulation of scrap rubber tires is an environmental issue which requires immediate attention. The accumulation of rubber causes serious environmental imbalances. It is known as 'black pollutant' (Xiong and Li, 2013). In the past, few studies have been conducted on scrap rubber tire-sand mixtures (Madhusudhan et al., 2017, 2020, 2021). These laboratory studies investigated the properties of scrap rubber tire-sand mixtures under various testing conditions, such as monotonic and cyclic triaxial, cyclic simple shear tests, etc. These studies show the favourable response required for their applications as

seismic base isolation materials of buildings. Few recent numerical studies (Boominathan et al, 2019) also investigate the same and concur on the merits of using these mixtures for a similar purpose. Hence, the potential of sand rubber mixtures needs to be further investigated for the stated application. This paper presents the experimental results related to the evaluation of the damping response of scaled physical models founded on scrap rubber tire-sand mixtures by carrying out 1g model tests. The present study further strengthens the benefits of using scrap rubber tire-sand mixtures as vibration dampening foundation materials for buildings.

2 MATERIALS USED FOR TESTING

The sand used for testing was locally available sand (Figure 1) used for the building construction. The rubber tire shreds (devoid of embedded steel wires) were obtained by shredding the tires in a tire shredding machine. The fine size rubber particles of desired size (less than 2mm) were obtained by (Figure 1). The grain size distribution of sand and rubber materials are shown in Figure 2. Table 1 presents the properties of sand and rubber tire shreds.



Figure 1. Materials used - sand and rubber tire shreds.

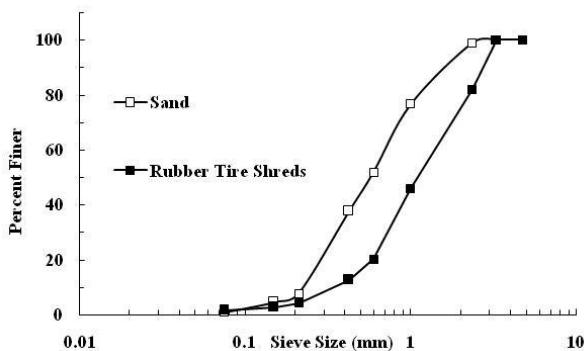


Figure 2. Grain size distribution of materials used.

Table 1. Properties of the materials used for testing.

Item	G_s	D_{10} (mm)	C_u	C_c	γ_{dmax} (kN/m ³)	γ_{dmin} (kN/m ³)
Sand	2.68	0.22	3.18	0.8	17.6	15.3
Rubber	1.14	0.35	3.57	1.12	5.2	2.8

3 EXPERIMENTAL SETUP, PROCEDURE AND ANALYSIS

The prototype structure considered has a plan area of 6 sq.m and consists of ground floor + up to 2 storeys (each storey 3m height). The steel model was made of square steel rods (beam size 10mm, column size 12mm) with each storey height 30cm. The footing size

of the model was 10cm x 10cm x 1cm. The scaling laws as proposed by Iai (1989) were adopted.

Foundation conditions consisted of 4 cases as shown in Table 2. Rigid connections were made between model footings and heavy steel sections in the fixed base case (Figure 3a). Other base conditions had the model structure founded on pure sand, 10% sand-rubber tire mixture (gravimetric) and pure rubber. In latter cases, the model was setup within a 1.5m diameter and 0.85m height steel tank internally covered with EPS strips. These strips were provided to prevent reflection of the vibrations from the boundaries. The procedure reported in Madhusudhan et al. (2017, 2020) was adopted to create a sand bed inside the tank. The dense sand bed was made in various layers with each layer given an adequate number of tamping.

Careful placement of the model structure footing was ensured in the foundation block to maintain the desired footing depth from the sand surface level. The test setup is shown in Figure 3(b).

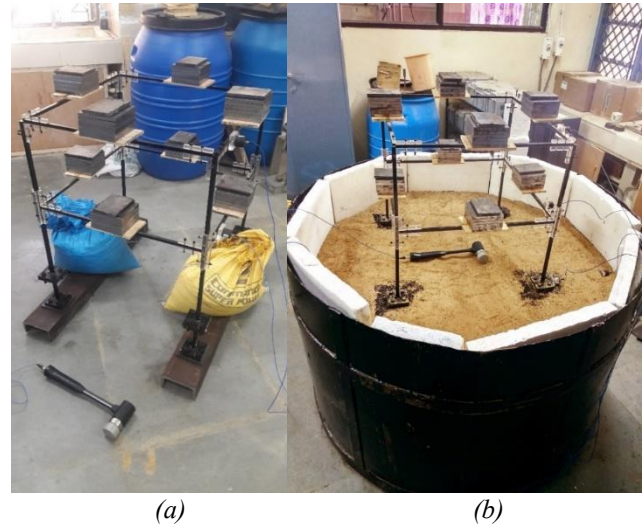
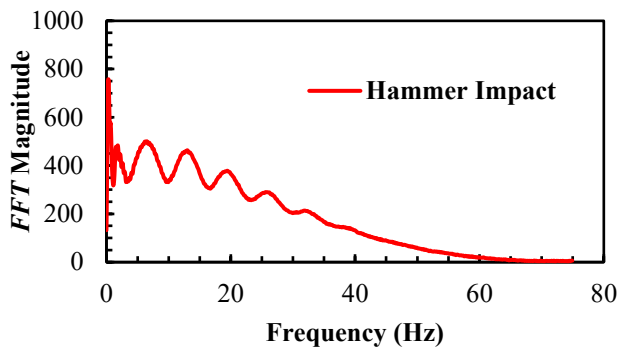


Figure 3. Test setup (a) Scaled model with fixed base (b) Scaled model structure placed on sand-rubber mixture.

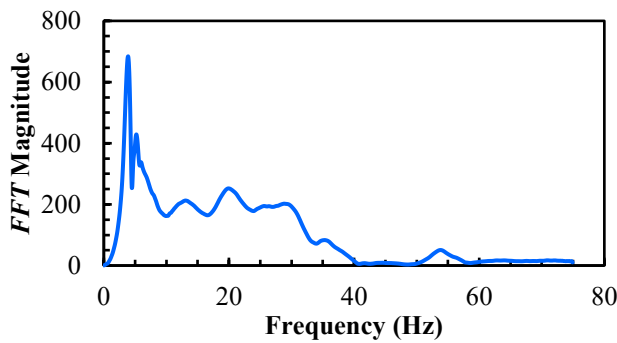
The impact was applied to the model structure using a PCB Piezotronics made impact hammer (086D20 model, 22.2kN capacity). The response of the structure was measured using PCB Piezotronics made accelerometers (393B04 model, cylindrical shape, dia 25mm, height 31mm, screw mounted). These sensors were attached to the model at various locations (floor levels, footing, and tank boundary). The hammer and the sensors were connected to the HBM made digital carrier frequency amplifier system. Notations $A1$, $A2$, and $A3$ were used for the sensors mounted on the ground, first-floor, and second-floor beam levels respectively.

The impact locations were at storey beam levels (middle of the beam). The resulting acceleration time

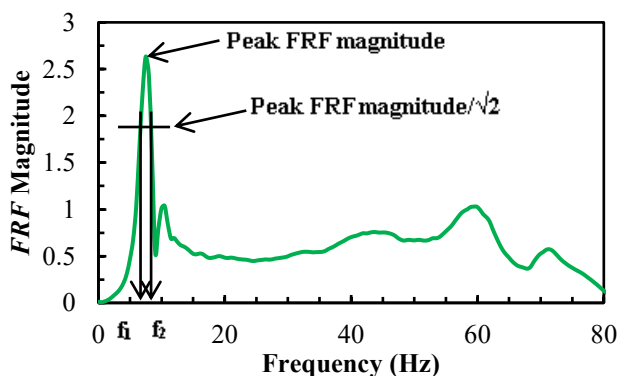
histories were recorded by the mounted sensors. They were further converted to the frequency domain using Fast Fourier Transforms (*FFT*). Further, the Frequency Response Function (*FRF*) is the ratio of the output response of the system and the input excitation given to the system. Both the output and input signals in the frequency domain i.e., the Fourier amplitudes were used to obtain the *FRF* plot as a complex spectrum of the system. Figure 4 shows the typical frequency response of a hammer impact, the corresponding acceleration response of the structure, and the resulting *FRF* magnitude plot calculated using the *FFT*s of hammer input and the acceleration response.



(a) *FFT of hammer impact*



(b) *FFT of an accelerometer signal*



(c) *FRF magnitude plot*

Figure 4. Estimation of the damping ratio from the *FRF* magnitude plot using half-power bandwidth method.

The damping ratios were estimated from the *FRF* plots using the Half-Power Bandwidth method (Chopra, 2023) as given by Equation 1.

$$D = \frac{f_2 - f_1}{2 * f_n} \quad (1)$$

where f_1 and f_2 are the frequencies corresponding to the peak *FRF* magnitude/ $\sqrt{2}$, and, f_n is the fundamental frequency of the system. The frequency corresponding to the peak of the *FRF* magnitude plot represents the fundamental frequency of the system

4 RESULTS AND DISCUSSION

Tables 2 to 4 present the damping ratio of the structure with different floors and hammer impact locations. (Note: Ground Floor is abbreviated as *GF*).

Table 2. Damping ratio of *GF* structure (*GF* hammer hit location).

Base condition	Load factor	Damping Ratio (%)	
		At A1	At A4
Fixed Base	NL	4.6	-
	1	4.5	-
	1.5	-	-
Pure Sand	NL	21.0	23.1
	1	11	-
	1.5	-	-
10% Mixture	NL	18.9	21.0
	1	16.1	-
	1.5	-	-
Pure Rubber	NL	11.5	10.6
	1	12.6	11.6
	1.5	14.4	13.3

Table 3. Damping ratio of *GF+1* structure (*GF* hammer hit location).

Base condition	Load factor	Damping Ratio (%)		
		At A1	At A2	At A4
Fixed Base	NL	-	-	-
	1	10.5	11.1	-
	1.5	16.3	14.3	-
Pure Sand	NL	7.3	10.4	8.6
	1	7.6	8.6	5.7
	1.5	-	-	-
10% Mixture	NL	13.9	13.6	10.8
	1	11.6	11.6	13.3
	1.5	5	12.3	14.3
Pure Rubber	NL	11.8	11.8	10
	1	15.7	-	16.7
	1.5	31.2	18.7	20

Table 4. Damping ratio of GF+2 structure (GF hammer hit location).

Base condition	Load Factor	Damping Ratio (%)			
		At A1	At A2	At A3	At A4
Fixed Base	NL	13.2	11.0	9.3	-
	1	8.2	16.7	11.3	-
	1.5	8.9	20.0	10.2	-
Pure Sand	NL	-	11.4	-	-
	1	18.2	-	-	-
	1.5	-	18.5	17.0	-
10% Mixture	NL	14.6	12.5	12.8	-
	1	17.8	14.3	14.3	13.5
	1.5	15.0	11.6	10.8	-
Pure Rubber	NL	16.5	15.8	-	12.0
	1	22.5	21.0	7.83	23.7
	1.5	12.5	16.2	14.6	36.7

At the outset, the damping ratio was found to be lowest for the structure whose base was fixed. This is because the displacements developed upon impact were the least in the case of a structure with a fixed base. This is in line with the known fact that at low strains, the damping ratio is minimal.

When the base condition of the structure was changed from fixed to pure sand, an increase in the damping ratio was observed. Further, for the structure with sand-rubber tire shred mixture foundation (10% mix), the damping ratio remained more or less the same as observed in the case of pure sand. However, in many cases, the damping values of the system were observed to increase. Interestingly, for the structures on the pure rubber tire shred block, the overall damping ratio was found to be comparatively less than that of the cases where the structure was founded on pure sand and the 10% sand rubber tire shred mixture. This observation is also supported by the experimental results from the laboratory element tests where the pure rubber tire shreds were found to show the least damping ratio in comparison with the damping ratio observed for pure sand and the 10% sand-rubber tire shred mixture (Madhusudhan et al., 2017, 2019, 2020).

5 CONCLUSION

The dynamic responses of scaled physical models were studied using impact hammer testing. The base conditions of the foundation and the loading on the models were varied. The results are highlighted in terms of the damping ratios.

The damping evaluated for the case of a model structure founded on a 10% sand-rubber mixture foundation block is higher than the cases where other materials are used in the foundation.

The present experimental study shows that the 10% sand-rubber mixture can be a promising material. The

results of the present study show that this mixture has a potential to act as a vibration dampening foundation material for low-rise buildings. However, future research is essential for more rigorous analysis under more realistic conditions.

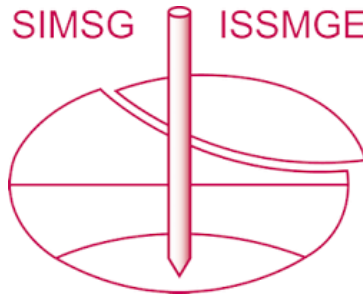
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