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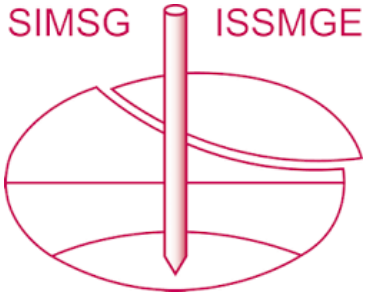

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1g model tests on buildings founded on sand-rubber tire shreds mixture

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ABSTRACT: The alarming rate at which the scrap rubber tires are generated, its uncontrolled disposal in the environment causing severe pollution are some of the major issues to be addressed. The disaster inflicted by the earthquakes on the low-rise buildings and the unavailability of an affordable low-cost isolation system demand immediate engineering attention. The past laboratory investigations show the potential for use of sand-rubber tire shred mixtures in various geotechnical applications. However, there is a lack of studies particularly on the use of these mixtures for the seismic isolation of buildings. In the present study 1-g laboratory model studies are carried out on the scaled typical low-rise buildings (consisting up to Ground+2 floor levels). Different base conditions such as fixed base and the one resting on sand-rubber tire shred mixture layer in a circular tank of 1.5m diameter and 0.85m height filled with sand are considered. A series of impact hammer tests were conducted on these scaled physical models instrumented with PCB Piezotronics make accelerometers. An HBM make digital carrier frequency amplifier with the data acquisition system is used to measure the impact force and the time histories of accelerations of the structure. The measured peak horizontal accelerations at the different levels of the structure show that the sand-rubber tire shred mixture possesses the adequate potential for their application as seismic isolation materials for low-rise buildings.

1 INTRODUCTION

The rapid accumulation of scrap rubber tires is a serious environmental issue which necessitates their usage in various applications. The existing seismic isolation systems are very expensive for their applications in low-rise buildings, especially in developed and underdeveloped countries. In view of the above, there is a need to find an alternative, low-cost and effective seismic isolation system. The past studies mostly considered conventional cyclic triaxial tests (Hazarika et al. 2010, Nakhaei et al. 2012, Ehsani et al. 2015, Mashiri et al. 2016a & b, Madhusudhan et al. 2017) and resonant column tests (Feng & Sutter 2000, Anastasiadis et al. 2011, Anastasiadis et al. 2012, Senetakis et al. 2012a,b) to find the strain-dependent dynamic properties of sand-rubber tire shred mixtures wherein the potential of the sand-rubber tire shreds mixtures as seismic isolation materials is discovered and supported by the experimental findings from the laboratory element tests. Overall this is not enough. Although based on the properties, the sand-rubber tire shred mixtures have potential, it is imperative to establish their suitability as an isolation material by testing a scaled physical model placed on this material. In view of this, the present study involves the impact hammer testing on the scaled physical model of a Ground+2 storey prototype building placed on the sand-rubber tire shred mixture block within a cylindrical tank. As a reference for comparison and to observe the isolation effect, the testing is also carried out on the model with fixed base conditions. The conditions of with and without the load on the structure are also studied.

2 MATERIALS

Uniformly graded locally available river sand (Figure 1) used for the construction of buildings is selected for testing. The steel wires present in the rubber tires were completely removed from the tires and further the tires are shredded in the shredding machine to obtain rubber shreds. These rubber shreds were further sieved through sieve no. 10 to obtain particles of fine size (less than 2mm) (Figure 1). Figure 2 shows the grain size distribution curves of sand and rubber tire shreds. The properties of sand and rubber tire shreds are summarized in Table 1.

The sand-rubber tire shred mixture with 10% rubber content by weight is established as the optimum mixture by the previous study of the authors (Madhusudhan et al. 2017) based on the results of the laboratory static and cyclic triaxial tests. Hence, the present study considers the testing on this sand-rubber tire shred mixture.

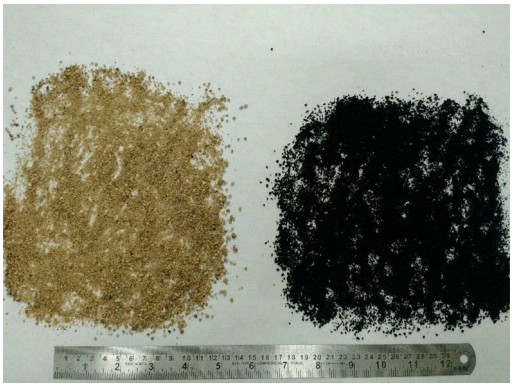

Figure 1. Pure sand and pure rubber tire shreds.

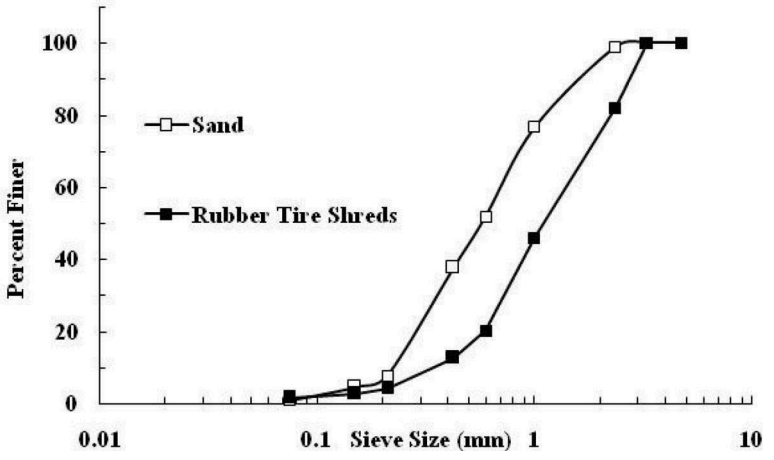

Figure 2. Grain size distribution of materials.

Table 1. Properties of the materials

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 TEST SETUP AND EXPERIMENTAL PROCEDURE

A ground+2 storey building of storey height of 3m and a plan area of $6m^2$ is considered as the prototype. The slab thickness is assumed as 150mm and the beams and columns are assumed to be made of ISMB 500 and ISMB 600 steel sections. The top storey slab thickness is taken as 120mm. The size of the footing is considered as 1m x 1m x 0.1m. Correspondingly, the steel model has a storey height of 30cm and the beams and columns are made up of square steel rods of 10 and 12mm size. The size of the model footing is 10cm x 10cm x 1cm.

The scaled physical model is fabricated in the fabrication unit of IIT Madras using square steel sections. The scaling laws as proposed by Iai (1989) are adopted and as shown in Table 2. The similitude relationships which are based on the geometry, mass, etc., as proposed by Iai (1989) assumes a continuous soil medium maintaining equilibrium at low strain deformations. The authors would like to clearly state that the according to Iai (1989), the validity of the proposed scaling laws is assumed within a number of approximations and idealizations, and specifically, under the assumptions mentioned in Rocha (1957). Therefore, they are not applicable for large strain involving the ultimate state of stability of soil structures and foundations, that are out of the scope of this work.

An alternative way of perceiving this is that the sand-rubber tire shred mixture layer can be prepared using the similar method both in the laboratory and the field (if adopted) which ensures similar conditions. It is reported in Iai (1989) that the effect of confining stress in soil is taken care of, if the recommended similitude relationships are used. Also, since the present study deals with the comparison of the absolute peak acceleration values (discussed in Section 4), the use of scaling factor to the acceleration or otherwise should make no difference to the conclusions drawn. Hence, the scaling factors are 1.0 for both the density of the soil and the measured acceleration responses. However, a scaling factor of 10 is applied to obtain the size of the model as it is essential to geometrically scale down the size of the prototype to fit the laboratory testing space.

In the fixed base case (Figure 3a), the footings are rigidly connected to heavy steel sections. Additional loads were also placed on these steel sections to prevent any kind of motion at the level of fixity. Another base condition is the model structure placed on the 10% sand-rubber tire shred mixture. In this case, the test setup consists of a steel tank of 1.5m diameter and 0.85m height. This tank is internally covered with the expanded polystyrene strips to simulate the vibration absorption boundaries. The sand is poured in this tank in various layers with each layer given the adequate number of tamping to achieve dense conditions in accordance with the procedure mentioned in Madhusudhan et al. (2017).

For the tests using 10% sand-rubber tire shred mixture, the depth of the footing is maintained as 10cm. The width of the mixture block is adopted as equal to the width of the footing plate, filled and compacted up to a depth of 10cm below the footing plate. The same mixture is also placed above the footing plate up to the surface level.

The model structure is carefully placed in the mixture block such that the desired depth of the footing is maintained from the surface level. Figure 3(b) shows the test setup. The loading plates were placed on the beams as shown in the figure. These loads on the beams and columns correspond to the scaled storey loads from the prototype. For the ground storey, the total load intensity on the footing is 58kPa and for the building with the ground and first storeys, the load intensity is considered as 111kPa of the prototype. For the structure up to the second storey, the load intensity is considered as 155kPa. The tests were also conducted only the framed structure with the absence of any loading plates to assess the effect of loading.

Table 2. Scaling laws (Iai, 1989)

Parameter	Scaling factor
Length	10
Mass density	1.0
Acceleration	1.0

(a) (b)

Figure 3. Experimental setup (a) Model with fixed base (b) Model placed on sand-rubber tire mixture

The PCB Piezotronics make impact hammer with a capacity of 22.2kN is used to apply impact on the structure. PCB Piezotronics make accelerometers attached to the ground, first floor, second-floor beam levels, footing and near the boundary of the tank and further connected to the HBM make digital carrier frequency amplifier system with Data Acquisition System are used to measure the response of the structure. The accelerometers connected to the ground, first floor and the second-floor beam levels are denoted as AC1, AC2, and AC3 respectively. The accelerometers connected to the footing and the one placed near the tank boundary are denoted as AC4 and AC5 respectively.

The impacts were given to the model structure at all the storey beam levels using the impact hammer and the resulting acceleration time histories are recorded by the accelerometers. Three trials were conducted for each case and the average was considered.

To examine the boundary effects during the testing, the typical acceleration records of all the accelerometers for a trial on the structure consisting up to the second floor are plotted as shown in Figure 4. It can be clearly seen that the response of AC5 (the boundary accelerometer) is negligible when compared with the pickups of AC1, AC2, AC3, and AC4 accelerometers.

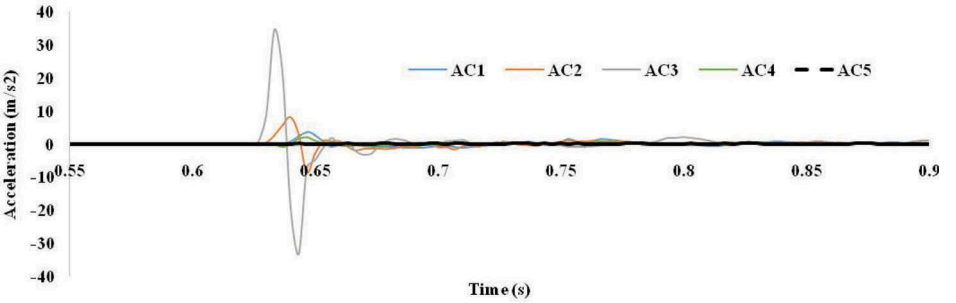

Figure 4. Acceleration responses to check for the boundary effects (AC5 boundary accelerometer).

4 RESULTS AND DISCUSSION

The recorded typical time histories of accelerations are shown in Figure 5. Figure 5a shows the effect of loading on the structure (L-Load, NL-No Load) on the measured accelerations. Figure 5b shows the effect of different base conditions (FB-Fixed Base, 10% sand-rubber tire shred mixture) on the acceleration response of the structure. Figure 5c shows the effect of number of storeys on the recorded accelerations.

Since a large amount of experimental data cannot be presented and explained in terms of the acceleration time histories, in the present paper, the results are presented in terms of the peak horizontal accelerations (PHA) obtained from the recorded accelerograms.

The peak horizontal accelerations obtained from the recorded time histories of accelerations are presented for the cases of no load (NL) and with loads (L) in Tables 3 to 5 for ground floor (GF) only, first floor (GF+1) and the second floor (GF+2) respectively.

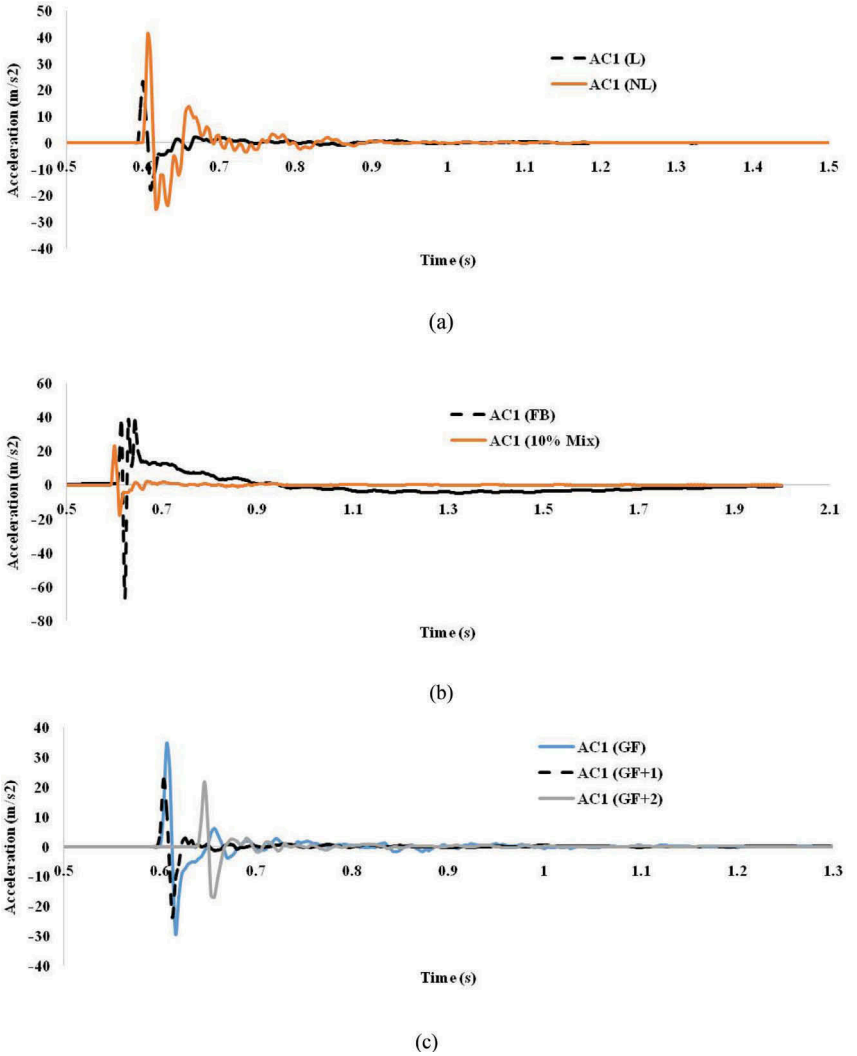

Figure 5. Typical acceleration time histories for ground floor (a) with and without the load on the structure (GF resting on 10% mix) (b) for different base conditions (c) for different storey levels (GF resting on 10% mix)

Table 3. Measured peak horizontal accelerations from impact tests on model structure with GF only

Load	Material	AC1 (m/s^2)	AC4 (m/s^2)	AC5 (m/s^2)
NL	Fixed base	76.96	-	-
	10% Mix	71.62	39.81	0.54
L	Fixed base	49.31	-	-
	10% Mix	47.28	29.41	0.59

L-Load, NL-No Load. The PHA values shown in Table 1 are obtained from impact at GF level

From the test results, considering the impact at the GF level, the PHAs (AC1) were observed to be in the range of 76.96 m/s^2 to 47.28 m/s^2 for the structure with GF alone, 48.5 m/s^2 to 23.54 m/s^2 for GF+1 and 39.39 m/s^2 to 29.77 m/s^2 for GF+2 structures. Similarly for the footings, PHAs lie in the range of 39.81 m/s^2 to 29.41 m/s^2 for GF, 22.99 to 14.67 m/s^2 for GF+1 and 28.23 m/s^2 to 22.55 m/s^2 for GF+2 respectively.

Likewise, considering the impact at the GF level, the PHAs for the GF+1 structure (AC2) were observed to be in the range of 38.25 m/s^2 to 17.82 m/s^2 for GF+1 and 34.6 m/s^2 to 9.25 m/s^2 for GF+2.

Similarly, considering the impact at the GF+1 level, the PHAs for the GF+1 level (AC2) were observed to be in the range of 90.03 m/s^2 to 50.41 m/s^2 for GF+1 and 63.6 m/s^2 to 39.45 m/s^2 for GF+2. For the footings, it was recorded as 19.22 m/s^2 to 11.33 m/s^2 (GF+1) and 17.76 m/s^2 to 11.1 m/s^2 (GF+2) respectively.

From the above, it can be observed that the PHA values are highest for the model structure with GF alone and decrease with an increase in the number of floors. Similar behavior can be observed from the results summarized in Tables 4 and 5 for the cases where the hammer impacts were given at the GF+1 and GF+2 levels respectively for different loading and base conditions.

Comparing the results for the for GF (AC1) with loading for different base conditions (Table 3), the PHA for the fixed base is found to be 76.96 m/s^2 whereas for the structure placed on 10% mixture it is 49.31 m/s^2. A reduction is observed in the PHA values when the base condition changes from fixed to that on 10% sand-rubber tire shred mixture. Similar behavior is seen for the GF+1 and GF+2 storeys as evident from Tables 4 and 5 irrespective of the hammer impact locations and loading conditions.

Further, it can be observed that for the case where there was no load on the model structure, the recorded PHAs were very high when compared with those values obtained from tests considering loading on the model structure. This is because the inertial forces developed in the loaded case is higher than those inertial forces developed in the no-load case. This kind of response is observed at all the floor levels.

It is obvious that there are many more factors which govern the dynamic response such as shear strain levels, the number of cycles of loading, frequencies and most importantly, the

Table 4. Measured peak horizontal accelerations from impact tests on model structure with GF+1 storeys

Impact location	Load	Material	AC1 (m/s^2)	AC2 (m/s^2)	AC4 (m/s^2)	AC5 (m/s^2)
GF	NL	Fixed base	48.50	38.25	-	-
		10% Mix	44.97	33.36	22.99	0.28
	L	Fixed base	25.26	20.16	-	-
		10% Mix	23.54	17.82	14.67	0.44
GF+1	NL	Fixed base	45.60	70.78	-	-
		10% Mix	37.42	90.03	19.22	0.33
	L	Fixed base	23.50	50.41	-	-
		10% Mix	16.37	66.80	11.30	0.23

L-Load, NL-No Load

Table 5. Measured peak horizontal accelerations from impact tests on model structure with GF+2 storeys

Impact location	Load	Material	AC1 (m/s^2)	AC2 (m/s^2)	AC3 (m/s^2)	AC4 (m/s^2)	AC5 (m/s^2)
GF	NL	Fixed base	39.39	34.60	25.33	-	-
		10% Mix	47.42	26.24	25.90	28.23	0.39
	L	Fixed base	33.24	17.03	6.46	-	-
		10% Mix	29.77	9.25	4.73	22.50	0.34
GF+1	NL	Fixed base	35.34	63.60	37.34	-	-
		10% Mix	28.37	61.25	41.81	17.76	0.23
	L	Fixed base	20.22	52.22	15.59	-	-
		10% Mix	9.97	39.45	13.55	11.10	0.27
GF+2	NL	Fixed base	23.32	37.30	83.16	-	-
		10% Mix	21.11	28.72	82.13	10.39	0.24
	L	Fixed base	8.55	17.53	62.03	-	-
		10% Mix	5.61	12.40	51.56	3.38	0.14

L-Load, NL-No Load

shear stiffness and the damping of the materials alone and also of the entire model structure-isolation material-foundation system together. The results of the present study, although expressed in terms of a single parameter i.e. PHA, shows that the 10% mixture behaves as a promising material for the seismic base isolation of low-rise buildings.

The accelerometer at the boundary (AC5) records very less PGA which implies that there are no boundary effects due to the reflection of the waves.

This study presents results from the testing carried out on laboratory scaled physical models in 1g gravitational condition. However, further studies such as centrifuge testing are necessary to evaluate the dynamic behavior simulating the real-time behavior. Future studies considering testing on the buildings isolated with the sand-rubber tire shred mixture to establish the in situ isolation behavior of these materials are also required to effectively show the isolation characteristics.

5 CONCLUSIONS

A series of impact hammer tests were conducted on the scaled physical model varying the number of storeys, foundation base conditions, and the loading. The results are enumerated in terms of the peak horizontal accelerations.

The following are the conclusions from the present study.

1) The peak horizontal accelerations decrease with an increase in the number of floors. This is independent of the hammer impact locations, the loading, and the base conditions.

2) The use of the sand-rubber tire shred mixture in the foundation leads to the reduction of the peak horizontal accelerations in comparison when the footings were fixed. This behavior is evident irrespective of the hammer impact locations and the loading conditions.

3) With the introduction of the load on the structure, the observed peak horizontal accelerations are found to reduce.

From the above conclusions, it can be inferred that the sand-rubber tire shred mixture with 10 percent rubber content by weight can be a promising material and has a potential to act as a seismic isolation material for low-rise buildings. However, further research is necessary to assess the same under more realistic dynamic stress conditions.

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