Seismic resilience of retaining walls backfilled with sand–tire chips mixtures

Bali Reddy Sodomi$^i$ Murali Krishna Adapa$^ii$ and S. Murty Dasakaiii)

i) Research scholar, Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati - 781039, India.
ii) Associate Professor, Department of Civil Engineering, Indian Institute of Technology Guwahati, Guwahati - 781039, India.
iii) Associate Professor, Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, India.

ABSTRACT
Seismic resilience of retaining wall with different sand – tire chips (STC) mixtures as backfill materials has been investigated. This paper presents the results of 1g-shaking table model tests carried out on retaining wall models of 600 mm height backfilled with different proportions of STC mixtures. The test program used two types of scaled earthquake input motions: Sikkim and South Napa. Model walls behaviours are presented in terms of incremental earth pressures acting on the wall and the associated displacements, as well as the accelerations at various locations of the model wall. Physical model test results revealed that the seismic incremental earth pressures, wall displacements, and accelerations were significantly reduced by using STC mixtures as backfill materials. Based on experimental model results, STC mixture backfills showed higher seismic resilience behavior compared to that of with conventional sand backfill.

Keywords: retaining wall, sand-tire chip mixture, displacements, earth pressures, seismic loading, resilience.

1 INTRODUCTION
Sustainability and resilience have been the important aspects in the recent years for infrastructure projects across the globe. Resilience is defined as continued performance under changing conditions, even if not in its best shape, to perform for its intended purpose even in harsh and unpredictable conditions (Shah et al. 2014). Thus, seismic resilience is conceptualized as the ability of an infrastructure facility to withstand earthquake-generated forces and demands and to cope with earthquake impacts (Bruneau et al. 2003). It is to be noted that a paradigm shift is essential to emphasis on designing in ‘resilience’ rather than in ‘resistance’. The resilience objective achieved by designing the ability of a buildings and infrastructure to absorb or avoid damage without suffering complete failure (Jennings et al. 2013). Earth retaining structures are one of the most common elements in infrastructure projects. Performances of retaining wall under static and seismic loading conditions depend upon the type of backfill soil and its strength and deformation properties. In place of traditional geo materials, new lightweight fills materials like shredded tire chips, geofoam, fly ash etc. are being explored now-a-days as alternative backfill materials. These lightweight materials are beneficial in reducing earth pressures and lateral displacements of the retaining walls. The objective of this paper is to examine the seismic resilience of retaining wall models backfilled with sand-tire chip (STC) mixture material.

A series seismic shaking tests on physical model walls with STC backfill are presented herein. STC mixtures with different tire chips proportions, such as 10%, 20%, 30%, 40%, and 50% are considered as backfill materials.

2 MATERIALS USED
Locally available cohesionless sand (S) and tire chips (TC) obtained from scrap tires, have been used in STC mixtures. Tire chips were of 10 mm square and 20mm length. Specific gravity and unit weight of the tire chips were determined as 1.08 and 6.45 kN/m$^3$, respectively. The sand has maximum and minimum dry unit weights of 16.1 kN/m$^3$ and 13.26 kN/m$^3$ with a specific gravity of 2.62. Tire chips were added to the sand in percentage by the weight of the mixtures: like, 10%, 20%, 30%, 40% and 50% that are represented as STC10, STC20, STC30, STC40 and STC50, respectively. Reddy et al. (2015) characterised pure sand (STC0) and different sand-tire chip mixtures through various index tests and large direct shear tests. Fig. 1 shows the variation of unit weight, void ratio and internal friction angle values of various STC mixtures. Unit weights of the pure sand and STC mixtures, in the model wall backfill, were maintained as shown in Fig. 1.
3 MODEL CONSTRUCTION AND INSTRUMENTATION

Retaining wall model of 600 mm height was constructed in a Perspex container of 1200 mm × 600 mm in plan and 1000 mm height. The model container is made of Perspex sheets of 10 mm thickness and braced by a steel frame made of angle steel sections that also facilitates for easy lifting and handling. The model wall of 600 mm high and 600 mm width was made with eight hollow rectangular steel sections, each of 75 mm height 25 mm width and 600 mm length, joined together using steel rods of 12 mm diameter. These steel rods were further connected to a bottom plywood base, forming a rigid connection. STC mixtures were prepared by manual mixing to maintain the selected TC percentage levels and are backfilled in stages using free falling technique, and compacting manually to achieve the target density. Instrumentations (pressure sensors and accelerometers) were placed at different locations while backfilling. The model wall after complete construction, was placed on a 1-g shaking table. The single axis shaking table (2.5 × 2.5 m in size) is intended to simulate horizontal shaking action associated with seismic and other vibration conditions. Shaking action is provided by a digitally controlled servo-hydraulic actuator of ±250 mm stroke. Fig. 2 shows schematic of model wall configuration and the locations of the various instrumentations.

To monitor the lateral deformations of the wall, three Linear Variable Differential Transducers (LVDTs) L1, L2, and L3 were positioned at 186 mm, 430 mm, and 580 mm from the top of the wall, respectively, on the front face of the wall. Four pressure sensors (each of 50 kPa capacity) were placed inside the wall, in contact with the facing at different elevations to measure horizontal pressures against the facing. Three accelerometers, each of ±1g capacity, out of which one (A1) attached to the Perspex container bottom and the other two (A2 and A3) were placed in the backfill as shown in Fig. 2. A soft foam sheet of 50 mm thick was provided at the end of the backfill to create a flexible boundary.

4 TESTING PROGRAM

Two different input earthquake motions were selected: (1) South Napa earthquake motion (SN), (2) Sikkim earthquake motion (SL). Details of the two earthquake motions are given in Table 1. Acceleration histories and FFTs of the scaled input motions are shown in Fig. 3. Model walls with different STC mixture backfills (STC10 -STC50) and pure sand (STC0) were tested for two earthquake motions simulated using the 1g shaking table. For a given seismic excitation, model wall response at various locations, in terms of accelerations, incremental earth pressures and wall face horizontal displacements were recorded during the excitations.

![Fig. 1 Variations of internal friction angle, dry unit weight and void ratio of STC mixtures (modified after Reddy et al. 2015)](image)

![Fig. 2 Schematic diagram of test wall configuration](image)

![Fig. 3 Scaled input earthquake motion records (a) Acceleration histories and (b) FFTs of the accelerations](image)

Table 1 Input earthquake motions

| Sl. No | Properties          | Earthquake Motions |
|--------|---------------------|---------------------|
|        |                     | South Napa 2014 (SN) | Sikkim 2011 (SL) |
| 1      | Magnitude (Mw)      | 6.0                 | 6.9               |
| 2      | Original PGA, g     | 0.85                | 0.123             |
| 3      | Scaled PGA, g       | 0.17                | 0.123             |
| 4      | Predominant frequency, Hz | 2.17              | 6.24              |
| 5      | Duration, s         | 70                  | 160               |
| 6      | Earthquake database | CESMD               | CESMD             |
5 RESULTS AND DISCUSSION

During seismic excitation, horizontal displacement histories at elevations of 125, 380 and 580 mm and incremental pressures acting on wall at different elevations were recorded. The incremental pressure is the measured increase in lateral pressure during dynamic excitation. Acceleration histories at a distance of 100 mm from the facing and at elevations 0, 300 and 600 mm are recorded. Typical variations of displacement and acceleration histories for SL and SN earthquake excitations in pure sand (STC0) backfill model wall are shown in Fig. 4 and Fig. 5, respectively. It can be observed from the figures that larger horizontal displacements and higher accelerations at higher elevations. Fig. 6 shows the variations of horizontal displacements, incremental earth pressures and acceleration amplification values along the height of wall for model with STC0 backfill for two earthquake motions.

Acceleration amplification factors were evaluated as the ratio of peak acceleration value at any elevation to the corresponding base peak acceleration value. It is observed that the incremental earth pressures, displacements, and acceleration amplification values are higher for SL motion compared to SN earthquake motion. This may be mainly due to the predominant frequency and duration of the motions. SL earthquake motion have high frequency range. Another point was that, SL earthquake motion is dominated by a large number of peak amplitude values. This is also one of the reason for observing the above response. Top horizontal displacement histories for SN earthquake motion (Fig. 7) were plotted for model walls with different STC mixtures and pure sand (STC0) as backfill.

As seen from the Fig.7, the peak top displacements and residual displacements are reduced for STC mixture model walls compared to that of STC0 model wall. The top displacements measured in case of retaining wall model for sand is 0.723 mm whereas it is reduced to 0.285 mm for 30% of tire chips which is nearly 60% reduction. The reduction of the top displacements with STC mixture show the seismic resilience behavior by minimizing the displacements,
which further will contribute towards the stability of the wall during seismic conditions. From the results of dynamic incremental earth pressure histories, significant reduction in pressure values is observed with increase in tire chips contents. The incremental earth pressure measured in case of retaining wall model for sand is 0.867 kPa whereas it is reduced to 0.126 kPa for 30% of tire chips. Which is almost 85% reduction.

Fig. 8 shows the variation of maximum values of displacements, incremental earth pressures, and acceleration amplification factors along the height of wall for all STC mixtures subjected to SN earthquake excitation. As seen from the figure, a significant reduction of earth pressures and displacements were observed in both the earthquake motions with addition of tire chips contents. From the Fig. 8(c) it is observed that the accelerations are amplified more on top of the wall in almost all the cases and the largest response acceleration of the model wall occurs in the case of sand (STC0), while the smaller responses occurred in the case of all STC mixtures (STC10, STC20 STC30, STC40, and STC50). Similar observations were also obtained for SL earthquake motion. When tire chips are mixed with sand, attenuation of the acceleration is observed. Maximum reductions of displacements were observed at STC30 mixture for both the earthquake excitations. This behaviour could be inferred due to the higher shear strength properties (friction angle) and lower deformation properties (void ratio) at STC30 as shown in Fig. 1. Another important point is when dynamic force is applied on model wall; tire chips may be absorbing the dynamic energy. Reduction of the horizontal displacements, dynamic earth pressures and acceleration implies a lower design load which results in lesser dimensions of the retaining wall. Based on all the above observations, shredded tire chips mixed with sand can be effective backfill material of retaining wall structures for seismic resilience and sustainable in terms of better performance in adverse conditions like earthquakes and also reduce the demand for traditional materials with the replacement by recycled scrapped tire chips.

6 CONCLUSIONS

Shaking table tests on retaining wall models backfilled with various sand- tire chip mixtures were conducted to investigate their seismic resilience. Model walls with STC mixture backfills showed significant reduction in horizontal displacements, incremental earth pressures, and accelerations compared to the backfill with pure sand. The reduction being about 60% for displacement and about 80% for incremental earth pressures. This behavior is attributed to the lesser unit weight and higher shear strength property of STC materials than that of traditional sand material. This indicate that the seismic resilience of retaining walls with STC mixtures as back fill materials is significant. Such mixture materials have absorbing capacity of earthquake induced force. Higher resilience behavior was observed for model walls with STC30 mixtures.

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