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Low cost damping scheme for low to medium rise buildings using rubber soil mixtures

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ABSTRACT

This study proposes to develop a low cost damping scheme using soil and waste tyre crumb mixture for low to moderate rise buildings. The proposed study consists of two parts, first characterizing soil and waste tyre mixtures and finding out the optimal size of tyre crumbs. The second part is to design the isolation system for low to moderate rise buildings and determine optimum dimension of the system. In the first part, a series of Unconsolidated Undrained triaxial test and large scale direct shear test have been carried out to select the optimum size of tyre crumbs from seven different crumb sizes. The Rubber Soil Mixtures (RSM) sample that provides higher shear strength, energy absorption capacity and stiffness is considered as the optimal size and further used in numerical simulations. In the second part, to analyze the damping effect of RSM, extensive numerical simulations have been carried out on the soil-foundation-structure system with varying thickness of RSM around isolated footing, varying percentage of rubber in RSM and input time history. The reduction in shaking level in terms of acceleration and inter storey drift, at different floor level with the use of RSM can be reduced by 40 to 50%.

Keywords: Rubber soil mixtures, numerical simulation, shear strength, seismic isolation

1 INTRODUCTION

A conventional earthquake resistance technology involves advancing the lateral strength, stiffness and inelastic deformation potential. Since the past century advanced earthquake resistance techniques are being developed not only to strengthen the structure, but also to reduce vibrations caused by earthquake generated forces to structures. Vibration reducing techniques involve the application of external devices among which base isolation systems in which rubber is substantially used as an essential element that has been principally suitable for earthquake resistance of low-to-medium-rise buildings (Ganeriwala, 1995). Hence, base isolation is considered the most effective tool for seismic isolation, considering passive devices for earthquake damping. Nevertheless, due to expensive implementation, these seismic isolation techniques are limited to only important structures. Considering its cost of implementation, particularly in developing countries, an effective seismic isolation technique cannot be afforded by a common man. Therefore, in this study a favorable and low cost seismic damping system has been suggested by providing a rubber-soil mixture (RSM) around the foundation of the structures to damp the vibrations due to seismic excitation. Any innovative system can be widely adopted in developing countries, if it is a cost effective technology (Tsang,

2008; Tsang et al., 2012). The main purpose of this study is to examine the vibration reduction due to new damping system. This study focused on understanding the damping reduction for a typical three storey building with isolated footings as these types of foundation are the most widely used in India.

The volume of scrap (waste) tyres, an undesired urban waste, is increasing every year. On an average, scrap tyres are generated one per capita annually in many of the countries (Edil & Bosscher, 1994), in particular developed countries, resulting in significant disposal problems. Utilization of rubber from scrap tyres has become one of the potential areas of research worldwide due to the unacceptable current disposal and stocking method of waste tyres. Many geotechnical applications were proposed for beneficial ways of recycling scrap tyres, of these major applications are its usage as a fill material in highway construction. Several studies are also available on the use of rubber/rubber sand mixtures as a novel application for seismic disaster mitigation for retaining wall and waterfront structures (Hazarika et al., 2008; Hazarika 2008). Reuse of scrap tyres would not only provide a way of disposing them, but also helps to solve some economic and technical problems for the sustainable environment. The use of waste tyres in geotechnical application may be feasible with a better understanding of the behavior of RSM. However the limited study was carried out to estimate

static and dynamic behavior of RSM in the laboratory for their effective use. In those studies the detailed investigation of the effect of different tyre-crumb sizes and tyre-crumb content on the shear strength of rubber-sand is very limited, which is recommended by many researchers (Promputthangkoon & Hyde, 2008).

In the present study, an attempt will be made to determine static and dynamic properties of sand-tyre mixtures considering different sizes and percentage of tyre crumbs through a series of laboratory experiments. Based on the strength and energy observation capacity, the optimum size of tyre crumbs is identified. RSM sample that provides higher shear strength, energy absorption capacity and stiffness is considered as the optimal size and has been used in the further investigation. An optimum percentage of tyre crumbs are about 30%, which may not be sufficient to use large quantities and get maximum benefit. Hence, for the selected optimum size, numerical simulations were carried out at a higher percentage of rubber which results in better damping capability of the RSM and higher deformation of the structures due to the compressible RSM. In order to enhance the load carrying capacity reinforcement studies are carried out on RSM.

2 OPTIMUM SIZE OF TYRE CRUMBS

The processed tyre crumbs are obtained from industry were sieved into groups of seven different sizes from A to G, tyre crumb sizes of 2.00 – 1.00 mm (passing the 2.0 mm sieve and retained on 1.00 mm sieve, designated as A), 4.75 – 2.00 mm (B), 5.60 – 4.75 mm (C), 8.00 – 5.60 mm (D), 9.50 – 8.00 mm (E), 12.50 – 9.50 mm (F), and 20.00 mm – 12.50 mm (G). The Unconsolidated Undrained (UU) triaxial tests and direct shear test were tested according to ASTM-D2850 (2007) and ASTM-D3080 (2011). The detailed explanation about the sample preparation and testing procedure can be found in Anbazhagan and Manohar (2015).
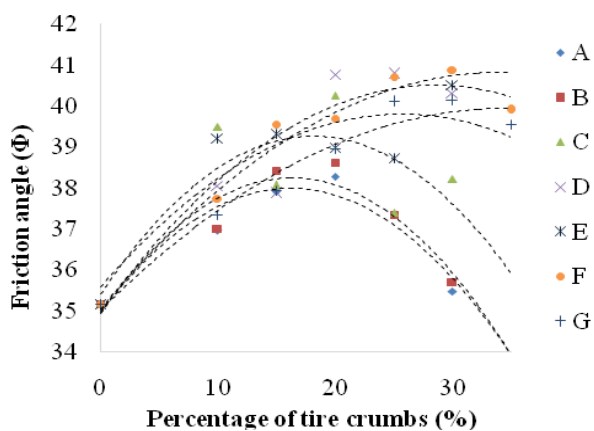

Fig. 1. Plot for variation of friction angle with different size and percentage of rubber.

In order to determine the influence of tyre crumb size on shearing properties, results obtained from direct shear tests were plotted between the angle of internal friction and percentage of tyre crumb. Fig. 1 shows a plot for variation of angle of internal friction with the percentage of tyre crumb for different tyre crumb sizes. From Fig. 1, it can be observed that the friction angle increases with increase in rubber content up to some percentage and then decreases. The peak friction angle for tyre crumb size A, B, C and D is observed at 20% tyre crumb content by volume, whereas for size E, F and G it is observed at 30% tyre crumb content. The maximum friction angle among all crumb sizes of tyre crumbs is obtained for tyre crumb size F at 30% crumb content for which friction angle varies from 35.17° to 40.87°, also it gives the maximum shear strength parameters. Shear strength of RSM is based on pressure imposed from sand grains to the tyre crumbs due to application of normal stress and the friction mobilized between sand-rubber, rubber-rubber, and sand-sand (Mahmoud, 2004).

The UU triaxial test results also demonstrate that the crumb size tended to be more effective in increasing the shear properties of RSM. Shear strength increases with increase in crumb size up to crumb size F, but for larger crumb size G, shear strength was found lower than that for crumb size F. Considering all the crumb sizes, crumb size F provides comparatively higher energy absorption capacity and stiffness. The area under the stress-strain curve up to a given value of strain is the total mechanical energy per unit volume consumed by the material while straining it to that value (Roylance, 2001). Hence crumb size F is considered as an optimum size, and is further used for numerical simulation with higher rubber content.

3 NUMERICAL ANALYSIS

In this study, a non-linear transient dynamic analysis of a 2-D finite element model of the soil-foundation-structure system has been performed to find out the optimum filling size of RSM. The building model has been generated considering the typical G+2 building in Indian design with 20 m rock depth, and the foundation is placed about 2.5 m below ground level. The beams and columns in the structure are modeled using 2-D frame elements concentrated at nodal points. The isolated footings and the soil column have been modeled using 4-noded 2-D plane strain plate elements. The finite element model is shown in Fig. 2. Mohr-coulomb failure criterion has been considered for the soil, the properties like cohesion and friction angle are determined through large scale direct shear test. The dynamic properties like shear modulus and damping ratio, required for assigning damping coefficients at the base of the soil column are determined using resonant column test. Considering the transmitting boundary condition, viscous dampers are implemented on the

base of the computational soil domain in order to mitigate the reflective effects of waves reflected from the rock surface. The Newmark beta method has been used to calculate the displacement, velocity and acceleration vectors. Rayleigh damping is used for the soil-foundation-structure system. This damping in the system is not frequency dependent and two sets of frequencies are selected so that the damping values vary in a minimum range.
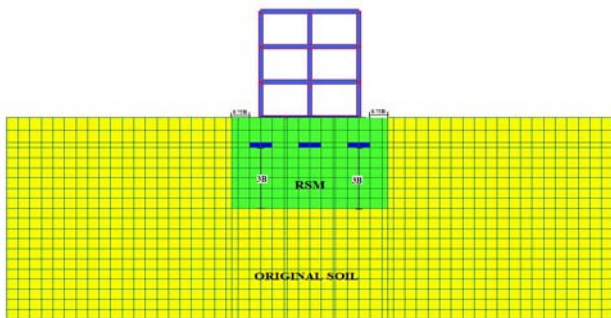

Fig. 2. Finite element model for the proposed seismic isolation method using RSM layer with RSM thickness 3m below the footing and 1.125m on sideways.

3.1 Properties of building model

The building model has a constant storey height of 3.5 m and bay width of 4 m. The material properties for all the beams and columns are of M20 concrete with Young's modulus 25 GPa and density 2400 kg/m^3. The cross-section for both beam and column is 0.23 x 0.4 m. The non-structural load (live load) on the beams is 5 kN/m^2. As per recommendations of Tsang, (2008) and Tsang et al., (2012) the lateral stiffness of the frame were increased by 2 times considering the influence of walls and other non-structural elements on the lateral stiffness of the frame. The properties of RSM obtained from laboratory test discussed above and Anbazhagan Manohar (2015) has been used here.

3.2 Input parameters

A parametric study has been carried out on a number of key variables, including side width (0B, 0.25B, 0.5B, 0.75B and 1.0B, where B is the width of
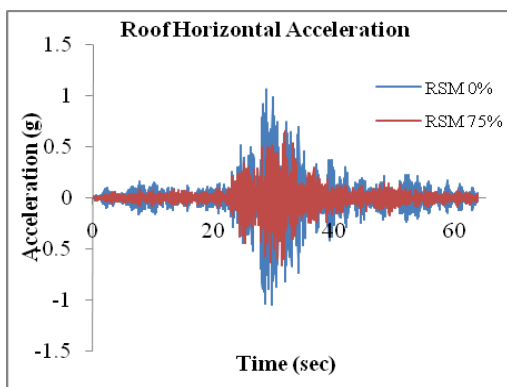

Fig. 3. Normalized horizontal acceleration for roof floor with 75% RSM, for RSM depth of 3B and width 1B.

footing) and thickness below footing (2B, 2.5B and 3.0B), rubber content in RSM (50% and 75% tyre crumbs), and frequency content of the input earthquake ground motions. Here acceleration time history data of Indo-Burma 1988 earthquake of Mw 7.2 and PGA 0.133 g, and Sikkim Gangtok 2011 earthquake of Mw 6.8 and PGA 0.161 g are used for analysis. It should be noted that only one input parameter is varied in each run, while keeping all other input parameters constant.

3.3 Output parameters

The peak acceleration, response spectral accelerations, average spectral accelerations and dominant frequency are estimated in finite element analysis. These are used to compare and evaluate the effectiveness of the proposed method at different floor levels. Fig. 3 shows a comparison of acceleration time history of the input motion and that estimated at top of second floor. Fig. 4 shows the corresponding spectral acceleration at roof level with normal fill soil and 75%
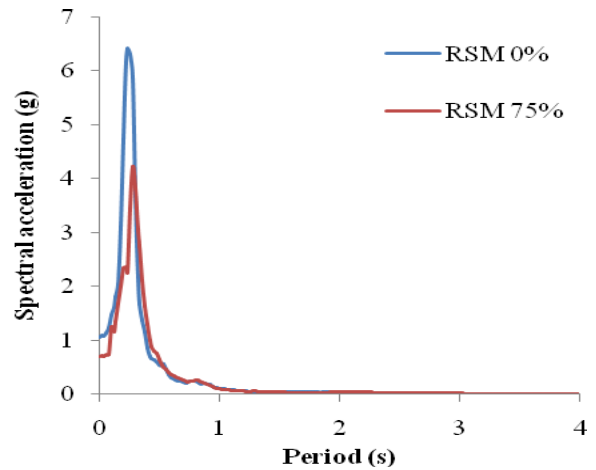

Fig. 4. Spectral acceleration for roof floor with 75% RSM, for RSM depth of 3B and width 1B.
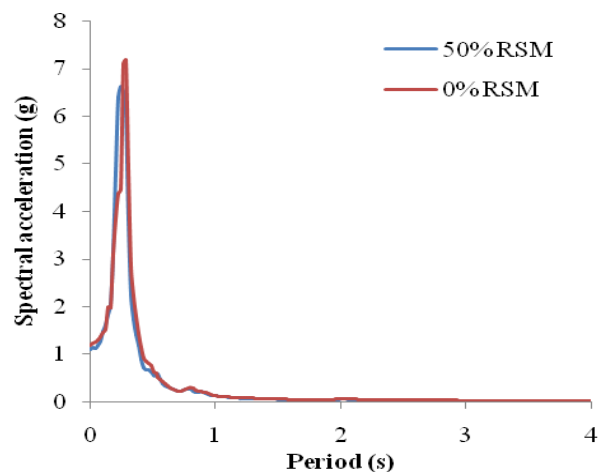

Fig. 5. Spectral acceleration for roof floor with 50% RSM, for RSM depth of 3B and width 1B.

RSM for Indo-Burma earthquake. The proposed method can reduce the horizontal ground accelerations effectively. Fig. 5 represents the spectral acceleration plot at roof level with 50% RSM. The percentage reduction in acceleration varies with the depth and thickness of RSM provided. Also from the numerical study it was found that the frequency content of input motion is the influencing parameter apart from percentage of rubber in RSM (50% and 75% rubber by volume).

The maximum reduction in acceleration in the present study was found for 75% RSM with thickness 3B and width 0.75B. On average, the reduction in acceleration was 20-30% for Gangtok earthquake motion and 40-50% for Indo-Burma earthquake motion for 75% RSM. However, for 50% RSM, the reduction levels were only 10-20% for both the earthquake motion. Thus the proposed scheme is region/site specific.

4 GEOSYNTHETIC REINFORCEMENT

Excessive deformation of RSM layer below footing was observed through numerical simulation due to compressible composite materials. With the increase in rubber content in RSM, the shear strength properties of RSM were reduced. In order to enhance the load carrying capacity without affecting the damping characteristics, reinforcement were introduced. Reinforcement study was carried out on three types of geosynthetic (geonet, geogrid and geotextile) with varying layers of reinforcement (1 to 4 layers) for three confining pressures. Typical stress-strain curve for reinforced RSM (75% RSM) with different types of geosynthetics for confining pressure of 100 kPa is shown in Fig. 6.
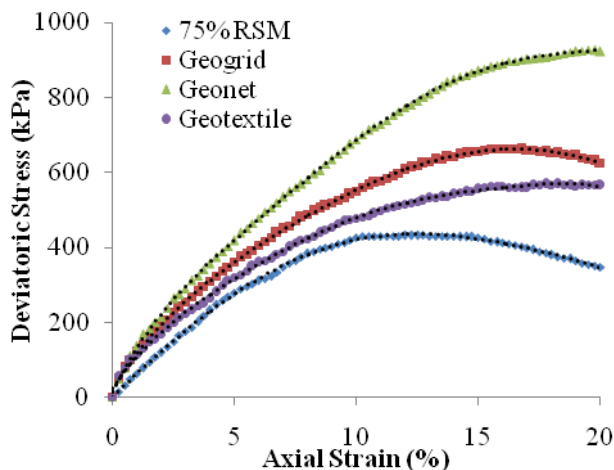

Fig. 6. Stress-strain curve for different types of reinforcement for 75% RSM.

The results indicated that, the geosynthetic inclusion increases the failure and ultimate strength of RSM significantly. Also, increase in strength varies with the different type of geosynthetics which can be clearly seen from Fig. 6. Test result shows that, for 50% RSM, RSM reinforced with geotextile resulted in the largest increase in strength, whereas for 75% RSM, geonets led to the highest strength. Geotextile inclusion increased the energy absorption capacity of RSM. With the increase in the layer of reinforcement and confining pressure resulted in higher shear strength and energy absorption capacity. The strength and energy absorption capacity increases by more than two times, for 50% RSM reinforced with 4-layers of geotextiles, and 75% RSM reinforced with 4-layer of geonets.

5 CONCLUSIONS

This study presents the detailed results of experimental investigation to select the optimum size of tyre crumb from seven crumb sizes. Crumb size F is considered as optimum size based on shear strength, energy absorption capacity and stiffness, compared to other crumb sizes. For the selected crumb size with higher rubber content numerical studies were carried out. Through numerical studies, it was noted that percentage of rubber in RSM, thickness and width of RSM around the footing and frequency variation of the input motion are the main factors which controls the damping characteristics of earthquake motion. For 75% RSM, the horizontal accelerations can be reduced by 40-50% for the selected thickness and width of RSM around the footing. Using 75% RSM causes excessive settlement and there is a need to improve the static properties without affecting the damping. Test on reinforced RSM were carried out, and the static properties are improved and settlement decreased. Finite element analysis will be carried out in future considering reinforced RSM.

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