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Investigating the Effect of Loading Frequency on the Dynamic Properties of Sand-Tire Powder Mixture Using Shaking Table Tests

H. Bahadori* , A. Khalili

Civil Engineering Department, Urmia University, Urmia, Iran

ABSTRACT: Nowadays, the use of waste tires has been expanded in various geotechnical projects to absorb and reduce the vibration caused by seismic and dynamic loads, and therefore it is crucial to study the effect of different parameters on their behavior and dynamic characteristics in combination with soil. So this study examined the effects of loading frequency on dynamic properties of sand-tire powder mixtures such as shear modulus (G) and damping ratio (D). A series of 1-g shaking table tests were performed on sand-tire powder mixture. Tire powders were added to the sand with 5%, 10%, 15% and 20% in gravimetric basis and with a relative density of zero were subjected to sinusoidal loading at frequencies of 0.5, 1, 2, 3, 5, 7 and 9 Hz and input acceleration of 0.1g and 0.3g. The results showed that in all cases, the increase in frequency in the same cycles increased the shear modulus and the damping ratio. Also, with increasing shear strain, the shear modulus of the mixture decreased, but the damping ratio increased. On the other hand, by increasing the tire powder, the value of the shear modulus is reduced, but the amount of damping ratio is increased.

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1. INTRODUCTION

Soil reinforcement is a useful technique for increasing the strength and stability of geotechnical structures and improving their performance. Several methods have been proposed for this purpose in various scientific sources and have been expanding over the years. The cost of each of these methods is very different, and the conditions under which they can be used depend on the nature, proximity of structures and construction installations. Attempts to find new methods of soil reinforcement and reduction of economic and administrative costs, as well as to reduce the environmental degradation by materials, have attracted the attention of researchers to the use of new recycled materials, such as the waste tire-derived materials. Due to its low specific gravity, high strength and compression, these materials have many applications in geotechnical projects such as reinforcing soft soil in road construction [1], controlling soil erosion [2], as aggregates in leach beds of landfills [3] and lightweight material for backfilling in retaining structures [4]. Another important application of waste tires in combination with soil, which has recently been of great interest, is their use as lightweight materials in retaining walls and embankments, machine foundations and railroad track beds in seismic zones. Having high damping characteristic, tires can be used as either soil alternative or mixed with soil to reduce vibration when seismic and dynamic loads are of great concern. So, to investigate the dynamic behavior of soil-tire mixture and various factors affecting it, several studies have been done.

In this paper, 1-g shaking table tests were employed to investigate the effect of loading frequency content on dynamic properties of sand-tire mixture. The response obtained from mixture samples during loading with different frequencies and input accelerations were used to generate hysteresis loops of tested samples at different strain amplitudes. Then, hysteresis loops were used to determine the shear modulus and damping ratio at different strain levels. Finally, the effects of loading frequency on the changes of each parameter (G and D) were investigated.

2. METHODOLOGY

A hydraulic shaking table with a single degree of freedom, designed and constructed at the Crisis Management Center of Urmia University, was used to conduct the experiments. Firoozkuh No. 161 sand was used in all the experiments and tire powders were used as a soil reinforcement material. Tire powders are made from discarded tires that have been broken into pieces and sieved by an industrial tire-shredder system. Also, accelerometers were used to measure the acceleration of the input to the sample as well as to record the acceleration caused by the input excitation at different depths of the soil sample. The displacement transducers (LVDT sensors) were also used to measure linear displacement. To record information, all sensors were plugged into a 16-channel dynamic data logger ART-DL16D. Samples were constructed in both unreinforced (pure sand) and reinforced form and

*Corresponding author's email: h.babadori@urmia.ac.ir

Table 1. Variable parameters in shaking table tests

Soil / Tire Powder	Frequency of loading (Hz)	Acceleration of loading (g)	Number of cycles	Total no.
Sand/0%	0.5, 1, 2, 3, 5, 7, 9	0.1, 0.3	30	14
Sand/ 5%	0.5, 1, 2, 3, 5, 7, 9	0.1, 0.3	30	14
Sand/10%	0.5, 1, 2, 3, 5, 7, 9	0.1, 0.3	30	14
Sand/15%	0.5, 1, 2, 3, 5, 7, 9	0.1, 0.3	30	14
Sand/20%	0.5, 1, 2, 3, 5, 7, 9	0.1, 0.3	30	14

with a relative density of zero. In reinforced samples, tire powders were added to the sand with 5%, 10%, 15% and 20% on a gravimetric basis. To prepare the sample, a wet tamping method was utilized in both the unreinforced (pure sand) and the reinforced (sand mixed with tire powders) specimens. In this method, first, the sand was mixed with 5% water. Samples were subjected to sinusoidal loading at frequencies of 0.5 to 9 Hz and input acceleration of 0.1g and 0.3g. Variable parameters in various experiments are listed in Table 1.

The main objective of this study is to obtain hysteresis loops for soil samples, using data recorded by accelerometers inside the soil in the shaking table tests, and then, to use these loops to determine the changes in the shear modulus and the damping ratio versus shear strain in the fixed number of cycles. In this study, the shear stress and shear strain values were calculated at 225 mm and 375 mm height from the model container floor and the hysteresis loops were plotted.

The shear stress at depth z is obtained from the solution of the integral as follows [5, 6]:

$$\tau(z)=\frac{1}{2}\rho z\left(\ddot{u}(0)+\ddot{u}(z)\right) \quad (1)$$

Where τ, ρ, z and $\ddot{u}$ are the shear stress, soil density, depth of soil and acceleration, respectively.

Also, the following equation is used to calculate shear strain [5, 6]:

$$\gamma=\frac{u_2-u_1}{z_2-z_1} \quad (2)$$

Where u is the displacement of soil.

3. RESULTS AND DISCUSSION

3.1. Shear Modulus

Shear modulus can be obtained through a hysteresis loop. The shear modulus for an arbitrary loop is obtained from the following:

$$G=\frac{\tau_{\max}-\tau_{\min}}{\gamma_{\max}-\gamma_{\min}} \quad (3)$$

Where τ and γ are the shear stress and shear strain, respectively.

The results showed that in the same cycles the shear modulus especially maximum shear modulus (G_{max}) increases as the frequency increases in all cases, and this increase is observed at lower frequencies and increases with increasing frequency. At a frequency of 9 Hz, the maximum shear modulus (G_{max}) has the most considerable value and at a frequency of 0.5 Hz, it has the lowest value. On the other hand, the shear modulus decreases with increasing shear strain. At a constant testing frequency, the sand mixture with 5% tire powder has a similar behavior to pure sand, and there is no significant difference between the shear modulus values. However, by increasing the tire powder, the shear modulus values of samples reduced so that the sample of sand with 20% tire powder has the lowest shear modulus between mixtures at all tested frequencies. As for the effect of input acceleration on the shear modulus, increasing the input acceleration increases the shear strain and consequently, decreases the shear modulus in all states. Also, at the higher input acceleration, the effects of tire powder on the shear modulus, notably the maximum observed shear modulus (G_{max}), is more pronounced.

3.2. Damping Ratio

The damping ratio for an ideal loop is obtained from the following equation. First, the energy lost per cycle (ΔW) and the energy stored in each cycle ($W_{elastic}$) must be calculated.

$$D=\frac{1}{4\pi}\frac{\Delta W}{W_{elastic}}=\frac{1}{4\pi}\frac{\oint \tau d\gamma}{0.125\times\Delta\tau\times\Delta\gamma} \quad (4)$$

The results show that, in all cases, the damping ratio increases with shear strain. At low strain levels, the damping ratio values at various frequencies are low and yet very close. At higher strain levels, the increase in frequency increases the damping ratio. Also, by increasing the tire powder, the damping ratio values of samples increase so that the sample of sand with 20% tire powder has the highest damping ratio between mixtures. On the other hand, the damping ratio increases with input acceleration. Also, the effect of tire powder on the increase in the damping ratio is more obvious at higher acceleration. For example, the difference between the maximum damping ratio (at the highest shear strain) under the acceleration of 0.3g between sand mixtures with 5 and 10% of tire powder is about 12%, while at acceleration of 0.1g this value is about 8%. The damping ratio variations versus the shear strain are irregular and inconsistent. By observing relatively irregular and non-uniform trends of damping ratios versus the shear strain, a new parameter has been presented as the mean value of the damping ratio (D_m) by Sabermahani et al. [7] to compare the values of the damping ratios of reinforced models with each other. The mean damping ratio (D_m) was obtained by averaging the damping ratio values. The results showed that the value of the mean damping ratio is increased with the increase in loading frequency, and by increasing the content of tire powders.

4. CONCLUSIONS

In the present study, the effects of loading frequency on the dynamic properties of sand-tire powder mixture were investigated using shaking table tests. The following conclusions were drawn:

1) The shear modulus, especially maximum shear modulus (G_{max}) increases with loading frequency in the same number of cycles. The trend is more obvious at larger frequencies.
2) The effect of loading frequency on the damping ratio at low levels of strain is negligible, and at relatively large strain levels, damping ratio increases with loading frequency.
3) Mean damping ratio (D_m) is increased with increasing loading frequency and tire powder content in all samples.
4) The shear modulus reduced by increasing the tire powder. The reduction in the mixture with 5% tire powder is very low compared to pure sand, and the highest reduction is observed in the mixture with 10% to 15% of tire powder.
5) By increasing the tire powder, the damping ratio values of samples increased so that the mixture with 20% of the tire powder has the highest damping ratio.
6) In all cases, the shear strain increased by increasing the amplitude of the input acceleration, and as a result, the shear modulus decreased and the damping ratio increased. Also, in higher input acceleration, the difference between the values of shear modulus and damping ratio of sand mixtures with tire powder is more visible.

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