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Effect of sand bags on vibration reduction in road subgrade

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ABSTRACT

Sand bags can serve as cushions for road subgrade, thereby reducing the impact of vibration on the surroundings. The effect of layered sand bags on vibration was studied experimentally. Under lateral confinement conditions, the expression for the effective soil pressure associated with medium sand at the sand bag epicentre was obtained. The expression was validated by comparing the calculated results with experimental data. The influence of the filling material in woven bags, source frequency, and number of exciters on vibration reduction was investigated. The source frequency is an important factor in evaluating the reduction effect of sand bags. For the same filling material, the larger the vertical stress, the greater is the peak acceleration. The influence of the number of exciters on the effective soil pressure is greater than that on the acceleration. The peak acceleration of medium sand with bags is considerably smaller than that without bags.

1. Introduction

Traffic-induced vibrations on the ground continue to challenge engineering research and practice and have received increasing attention in recent years. Such vibrations might affect the normal operation of nearby precision instruments. They might also disturb the lives of people residing in buildings near the road. In urban road subgrade, sand bags can be used as a wave barrier that can prevent the adverse effects of vibrations on the surroundings.

Over the past two decades, many researchers have paid a special attention to the dynamic responses and deformations of the road or subgrade under traffic loads. Liang et al. [1] established a vehicle-subgrade vibration model and analysed the main factor affecting the elastic deformation of the track. They suggested that the subgrade should be strengthened when the subgrade stiffness was less than 10 MPa. Chai and Miura [2] analysed the permanent settlement of the road on soft subsoil under traffic loads. The results showed that the depth significantly affected by traffic loads was around 6 m below the base of the embankments. Hanson and Singleton [3] investigated the performance of ballast mats on passenger railroads by developing a simplified prediction procedure. Their results showed that the model could predict the negative insertion loss at resonance on the condition of the light rail vehicle. Lu et al. [4] investigated the traffic-load-induced dynamic stress and deformation of a layered road structure using the transmission and reflection matrices method. They found that most of the stresses were imposed and dispersed by the road pavement. Afterwards, they [5,6] proposed a coupling model to calculate the dynamic responses of the embankment. Their results indicated that the dynamic responses of the embankment were sensitive to the variations of the pavement rigidity. Kouroussis et al. [7] developed a hybrid experimental-numerical approach to predict the ground-borne vibration propagation. The capability of this approach was proved by the studied case. Thompson et al. [8] investigated the effect of stiffening subgrade beneath the railway track on vibration mitigation. They found that a stiffened subgrade could provide benefit above around 10 Hz for the ground with a 6 m deep soft layer. Ngo et al. [9] used the discrete element method (DEM) to model the deformation behaviour of geocell-reinforced subballast. Their results showed that the geocell reduced the vertical and lateral deformation of subballast assemblies at any given frequency. Nimbalkar and Indraratna [10] used geosynthetics to improve the performance of ballasted rail track. The results showed that the geogrids were effective when the aperture size of them was in the range of 1.1 times the mean particle of the ballast.

Because sand bags have many advantages such as a wide range of materials, low cost, and convenient construction, they can be used as a cushion for road subgrade to reduce the impact of vibration on the surrounding environment. A number of numerical studies and field tests on the vibration isolation efficiency of soil bags can be found in the literature. For example, Matsuoka and Ando [11] studied the effect of layered soil bags on ground vibration. The results showed that the layered soil bags produced greater vibration reduction at the epicentre than at the sides. Tantono and Bauer [12] focussed on the interaction

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between the filling material and the bag on the evolution of the mechanical behaviour of the soil bag structure. Nakagawa et al. [13] identified the vibration reduction effect of the Solpack method by performing experiments and field inspections. Ansari et al. [14] analysed the mechanical behaviour of soil bags subjected to vertical and horizontal cyclic shear loading using the finite element method. Their work specifically took into account the active contact kinematic constraints at the soil-bag interface. Ye et al. [15] evaluated the vibration reduction effect of soil bags using field testing and a numerical method. The results showed that the damping effect depended strongly on the position of the vibration source. Ebrahimian *et al.* [16] studied the deformation behaviour of cohesionless granular soil using a micro-polar continuum approach and obtained the results for soil behaviour under large shearing movement. Wang and Wang [17] used the discrete element method to investigate the vibration reduction effect of a soil bag by developing an energy dissipation equation. The results showed that a high percentage of the soil bag surface and the particles inside it absorbed energy in the form of wave-shaped fluctuations during loading and unloading. Liu et al. [18] investigated the effectiveness of soil bags in reducing vibration through laboratory tests. They found that the soil bags had a high damping ratio and variable horizontal stiffness.

The above-mentioned studies indicate that sand bags can be used as an isolation barrier to reduce vibrations and that layered sand bags provide a useful construction method for this barrier. However, the influence of various filling materials in woven bags on vibration reduction under complex loading conditions has not been clearly understood, in part because of the complexity of wave scattering in sand bags. Therefore, in this study, a vibration reduction model consisting of sand bags was developed as a barrier for road subgrade. Under lateral confinement conditions, the expression for the vertical effective soil pressure associated with medium sand at the epicentre of the sand bags was obtained. The expression was validated by comparing the calculated results with experimental data. Furthermore, a parametric study was conducted to investigate the effect of different filling materials in woven bags, the source frequency, and the number of exciters on vibration reduction.

2. Test profiles

2.1. Test device

The test equipment includes a vibration testing device and an external data acquisition system. The vibration testing device (Custom Made, ANCO Engineers, Inc.) [19] mainly consists of a model groove, hydraulic power system, and host control system (Figs. 1 and 2). In the experiment performed using this test equipment, a custom-made model box was used instead of the model groove to study the dynamic response characteristics of the sand bags. The vibration behaviour of the foundation was studied by measuring the sand acceleration and stress between the sand bag layers. The settlement of the sand bags was analysed by measuring the displacement at the top of the model box using a displacement metre. External data acquisition was carried out using a dynamic signal acquisition system (DH5922, Donghua Testing Technology Co., Ltd.).

2.2. Test materials

In this experiment, white woven bags made of polypropylene geocomposites were used as the test materials. The main mechanical properties of these bags are listed in Table 1. The materials contained in the woven bags were fine sand, medium sand, and coarse sand with mass densities of 1571, 1665, and 1725 kg/m^3, respectively. The particle grading curves for the three types of sand are shown in Fig. 3.

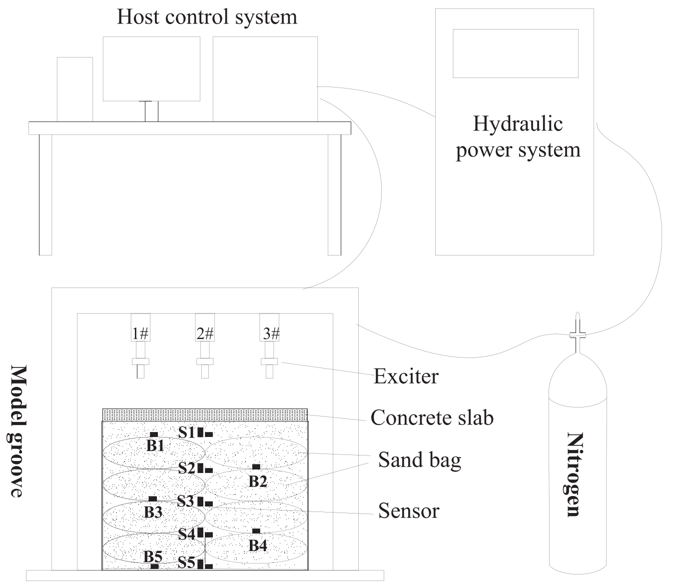

Fig. 1. Diagram of model groove under traffic stress.

2.3. Test schemes

The main factors that affected vibration reduction were the filling material in woven bags, vibration frequency, amplitude, and number of vibration exciters. The test protocols based on different combinations of these four factors are listed in Table 2. The typical size of each sand bag was 40 cm × 40 cm × 12 cm. The weight of each sand bag was 20.0 kg. The sand bags were stacked in piles of four. The gaps between the sand bags were filled with the same material as that in the bags; this filler material was used to stabilise the test components, as shown in Fig. 4.

The main test components used in this experiment were three-way capacitive accelerometers, soil pressure cells, and displacement meters. Five accelerometers, which were fixed in special wood chips, were placed at the epicentre, and the points at which these accelerometers took measurements were named as S1, S2, S3, S4, and S5 from the bottom to the top. The adjacent spacing between two accelerometers was 15 cm. At the same time, a soil pressure cell was fixed to each wood chip. Five other soil pressure cells were staggered and placed between the sand bag layers. They were marked as B1, B2, B3, B4, and B5. Four displacement meters were placed on the four corners of the concrete panel. The layout of the test components is shown in Fig. 5.

3. Test results and analysis

To investigate the vibration reduction effect of sand bags, fine sand, medium sand and coarse sand were first filled in polypropylene woven bags separately. Then, the bags were sealed using a portable sewing machine and placed in the model box. Each set of sand bags was subjected to maximum vertical stress of 2500 N, 5000 N and 7500 N, separately. The input stress is expressed as follows:

$$Q_t = q_0 \times |\sin(\pi f t)| \qquad (1)$$

where f is the frequency of the vibration source (Hz), t is the time (s), and q_0 is the amplitude of the vertical stress (N).

3.1. Response of the system with the number of loading

Fig. 6 shows the effective soil pressure versus number of loading at different depths (15 cm, 30 cm, 45 cm and 60 cm) for vibration frequency $f = 10$ Hz. At the initial stage of loading, the effective soil pressure increases rapidly at four depths as compaction occurs. When the number of loading exceeds 200, the growth rate of the effective soil