Construction and Building Materials 118 (2016) 104–115

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Dynamic properties of polyurethane foam-sand mixtures using cyclic triaxial tests

Iman Golpazir [a,*], Abbas Ghalandarzadeh [b], Mohammad Kazem Jafari [c], Mehdi Mahdavi [b]

[a] Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] School of Civil Engineering, College of Engineering, University of Tehran, Tehran, Iran
[c] Geotechnical Engineering Research Center, International Institute of Earthquake Engineering and Seismology, Tehran, Iran

HIGHLIGHTS

- Polyurethane foam can be considered as a potential alternative for reduction of seismic earth pressures.
- In mixtures samples, damping ratio is highly affected by the foam mass.
- The damping ratio and the shear modulus of pure foam increases and decreases respectively, with an increase in the initial deviator stress.

ARTICLE INFO

Article history:
Received 23 February 2015
Received in revised form 21 April 2016
Accepted 3 May 2016
Available online 12 May 2016

Keywords:
Polyurethane foam
Cyclic triaxial test
Damping ratio
Shear modulus
Compressibility

ABSTRACT

Reducing the static and seismic earth pressures on geotechnical structures, such as retaining walls, bridges abutments and buried pipes, using compressible materials is a novel idea which has received increased consideration during recent years. Despite the high compressibility of injectable polyurethane (PU) foams, their performance as a compressible inclusion material has not yet been studied. This paper presents results from a series of cyclic triaxial tests to investigate the dynamic properties of PU foam and PU foam-sand mixtures at intermediate to large strains. Furthermore, the effect of various parameters including initial deviator stress, static confining stress and foam-sand mixing percentage, on damping ratio and shear modulus are identified. The laboratory test results indicated that in pure foam, the damping ratio attenuated in elastic strain amplitudes, which remained constant once the stress was increased to near the yield point. The results of the tests on the foam-sand mixture samples with various mixing ratios demonstrated that the variation in damping ratios is a function of foam mass. So that for specimens with 5% PU foam, after a relative decrease, the damping ratio increased in the cyclic shear strain amplitudes more than 0.03–0.05%. In addition, it was observed that the dynamic behavior of the mixture is significantly affected by the content of injected foam and also confining stresses (proportional to the depth of the treatment zone).

1. Introduction

Improving the seismic responses of various geotechnical structures such as retaining walls, bridges abutments, machinery foundation and buried pipes is an ongoing issue that has been heavily researched in order to identify novel solutions or improve upon methods already established. Isolation and absorption of vibrations is one such method that has been implemented by establishing an insulator around geotechnical structures or the vibration sources. If the purpose is to absorb vibrations and reduce dynamic earth pressures, implementing a seismic buffer with a compressible material between the soil and the geotechnical structures is an appropriate solution [1,2]. In this method, with increasing earth pressures during earthquake, the seismic buffer is compressed and a part of the dynamic pressure dissipates as strain energy. Within the last two decades, comprehensive empirical [2–8] and numerical [1,9–15] studies have been conducted on the performance of compressible inclusions, and the effectiveness of these inclusions has been confirmed to improve the dynamic behavior of various geotechnical structures, specifically retaining walls.

In most previous studies, tire chips, tire chips-sand mixtures and specifically expanded polystyrene geofoam (EPS) blocks were utilized as the compressible inclusions. The choice of such materials is based upon their physical, mechanical and economical characteristics. The investigation of characteristics of tire chips and EPS

* Corresponding author.
E-mail address: i.golpazir@gmail.com (I. Golpazir).

http://dx.doi.org/10.1016/j.conbuildmat.2016.05.035
0950-0618/

Table 1
Comparison of the properties of PU foam and EPS foam.

Properties	PU foam (Current study)	EPS15 (ASTM D 6817-06)	EPS29 (ASTM D 6817-06)
Density, ρ (kg/m^3)	31.3	14.4	28.8
Initial elastic modulus, E_i (MPa)	2.6	2.5	7.5
Compressive resistance @ 1% axial strain, $\sigma_{y(1\%)}$ (kPa)	25	25	75
Compressive resistance @ 5% axial strain, $\sigma_{y(5\%)}$ (kPa)	71	55	170
Poisson's ratio, υ	0.02	0.08 [a]	0.16 [a]

[a] Estimated from empirical relationship by Horvath [19].

geofoam blocks under seismic excitations indicated that due to a low modulus of elasticity, a high compressibility and a damping ratio comparable to sand backfill, such materials are considered to be an ideal choice for compressible inclusions [3,11,16,17]. The implementation of compressible inclusion using tire chips or EPS geofoam blocks is a simple and valuable solution for improving the seismic response of under construction retaining walls. Nevertheless, the applicability of this method for rehabilitation and treatment of existing retaining walls requires excavating long trenches behind the backfill. So, this option is not appropriate for improving the seismic response and treatment of existing walls due to probable temporary instabilities of such trenches (specifically in collapsible soils). Moreover, for existing structures behind the wall sensitive to displacement, using compressible inclusions with such materials is not justifiable. Injectable polyurethane (PU) foam has high compressibility and its mechanical properties is very similar to those of EPS geofoam. Table 1 compares the mechanical properties of PU foam obtained from uniaxial tests (conducted in the current study) with those of EPS29 (with a similar density to the PU foam) and EPS15 geofoam (used as seismic buffer in several previous studies) obtained from ASTM D 6817-06 standard [18]. As shown in this Table, PU foam has acceptable properties to be considered as a compressible inclusion. The injectability of PU foam makes it appropriate as a compressible inclusion between the backfill and an existing wall without the necessity of excavating the long trenches (as a local injection treatment). Moreover, using PU foam, it is possible to construct the composite buffers (PU foam-sand mixtures) as a compressible inclusion in proportion to acceptable displacements of existing structures behind the retaining walls or under machinery foundations (performance based design approach). Previous studies regarding seismic buffer materials, such as tire chips, indicated that using tire chips-sand mixtures with an appropriate mixing ratio reduces the permanent displacement of retaining walls significantly (more than 60%) in addition to maintaining the attenuation efficiency [5]. Furthermore, using such mixtures reduces disposal cost.

Polyurethane foam is a type of organic polymer made up of closed or open cellular structure that can be classified into three groups: flexible foam, rigid foam and integral skin foam [20]. PU foam produces a high amount of carbon dioxide during chemical reaction with water or other blowing agents. The produced carbon dioxide is captured within the inner space of the polymer, and by applying pressure on the polyurethane cell walls, volume is increased and density is decreased. The physical and mechanical properties of polyurethane depend on its density as PU foam exhibits different behaviors proportional to the density. In geotechnical applications, PU foam is mostly used as an insulator and as a sealant layer. In addition, the effect of this material has been studied for other purposes, such as providing a decrease in the swelling potential of expansive soils and constructing wave barriers to decrease the effects of vibration sources such as machinery foundation [21–23].

According to the mentioned reasons, polyurethane foam has primary characteristics necessary for compressible inclusion materials. For more accurate evaluation of PU foam performance as a compressible inclusion, it is necessary to investigate the dynamic behavior of PU foam as well its efficiency on the seismic treatment of geotechnical structures by numerical analysis and physical modeling. Most previous investigations have focused on the PU foam properties in static or impact loading conditions [24,25]. Clearly, evaluation of a compressible inclusion by numerical analysis requires the identification of cyclic behavior and determination of the dynamic parameters of the material (damping ratio and shear modulus). In this paper, the cyclic behaviors of flexible PU foam and foam-sand mixtures have been studied using cyclic triaxial tests. Cyclic behavior of foam-sand mixtures has been studied for the sake of evaluating the effect of PU foam injection foam into backfill to potentially identify an appropriate mixing ratio in relation to earthquake intensity (performance based design) using numerical analysis in future studies. Furthermore, the effect of various parameters, such as the initial deviator stress (isotropic and anisotropic states), the static confining stress and the mixing ratio on dynamic properties of mixtures have been studied.

2. Test materials

In this study, crushed sand (produced by Metosak Inc.) was used to produce PU foam-sand mixture samples. Fine-grained sand (passing through a No.40 sieve) was removed to allow better penetration of foam into the voids and provide more homogenous specimens. The portion remaining on No.4 sieve were also removed, as the largest particle size should be smaller than $\frac{1}{6}$ the specimen diameter based on the ASTM D 3999-91 specifications [26]. Fig. 1 plots the resultant particle size distribution curve. This soil is classified as poorly graded sand (SP) according to the unified classification system [27] as the coefficient of uniformity, C_U, is 3.85 and the coefficient of gradation, C_C is 1.13. The PU foam used in this investigation includes flexible single-component foam with

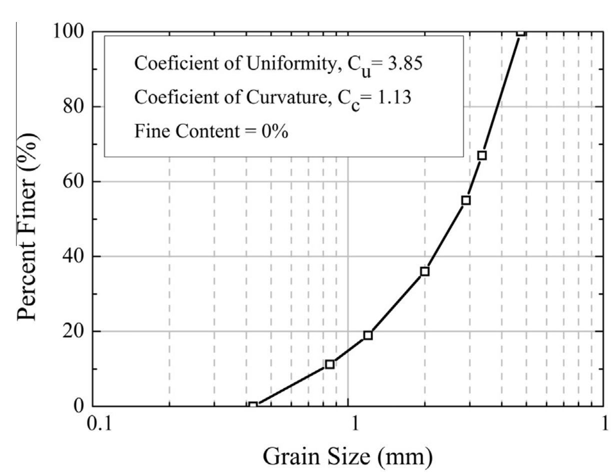

Fig. 1. Particle size distribution of sand.