Dynamic Viscoelastic Properties of EPS Geofoam from Cyclic Uniaxial Tests with Initial Deviator Stress

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Abstract

This paper addresses the influence of initial (static) deviator stress on measured dynamic viscoelastic properties of EPS geofoam in cyclic uniaxial tests. The experimental results were compiled into normalized Young's modulus and damping ratio versus cyclic axial strain amplitude relationships. Normalized modulus curve appears to be sensitive to the static deviator stress, displaying a more pronounced decay at smaller static deviator stress levels. On the other hand, no clear influence of the static deviator stress on the measured geofoam damping ratio could be discerned. Additionally, damping ratio showed a decreasing trend with increasing cyclic axial strain amplitude for a range of cyclic axial strain amplitudes up to about 0.5%.

INTRODUCTION

Recent research demonstrated that expanded polystyrene (EPS) geofoam can be utilized as an efficient compressible inclusion to reduce the seismic earth pressures against rigid retaining walls (e.g., below grade building walls, bridge abutments, restrained walls, gravity walls). Vertical EPS panels installed against such structures may act as seismic buffers attenuating the dynamic wall thrust during an earthquake. Results from static finite-element analyses of rigid non-yielding retaining walls with geofoam inclusion indicate that the geofoam panel behind the rigid wall is subjected to various horizontal static compressive stresses due to the static lateral earth pressure acting against the wall [1, 2]. EPS cylindrical specimens tested in uniaxial compression may be regarded as small elements of the geofoam panel with the axial direction of testing perpendicular to the wall and subjected to the static compressive stress. Thus, the cyclic uniaxial test with initial (static) deviator stress is appropriate to characterize the dynamic behavior of the EPS geofoam buffer under horizontal earthquake shaking. The present experimental study aims at providing a better understanding of the effect of initial deviator stress on measured dynamic viscoelastic properties of EPS geofoam in cyclic uniaxial tests. The experimental program involved non-elasticized EPS cylinders with a density of 25 kg/m^3 denoted herein as EPS25. Tested samples had a diameter (d) of 100 mm and a height to diameter (h:d) ratio of 2:1.

TESTING PROCEDURE

In the cyclic uniaxial compression tests, an initial (static) deviator stress (σ_{ds}) with a magnitude greater than the amplitude of the applied cyclic deviator stress ($\Delta\sigma_{dc}$) was imposed on the specimen prior to starting the cyclic loading phase in order to maintain the cyclic stresses in the

compression range. In order to maintain creep strains under static loading conditions at a minimum (insignificant) level, the magnitude of applied static deviator stress in cyclic uniaxial tests was selected to achieve static axial strains not greater than about 1% which represents the elastic limit strain for EPS geofoam. Cyclic testing phase started after the specimen had attained equilibrium (i.e., creeping of the material has ceased) under the applied static stresses. During each cyclic test, a uniform sinusoidal load characterized by a frequency of 1.5 Hz was applied.

EXPERIMENTAL OUTCOMES

Figure 1 is a graphical illustration of the Young's modulus (E) and energy quantities (W_d, W_s) required in damping ratio (D) computations that can be obtained from a viscoelastic hysteresis loop describing one complete cycle of loading. These parameters are calculated in relation to a local coordinate system that has the origin at the center of the hysteresis loop. Young's modulus (E) is defined as the secant modulus representing the slope of a line drawn through the origin and the point of load reversal. Damping ratio (D) characterizes material ability to dissipate energy by viscous mechanisms, and employs the dissipated energy per unit volume in one hysteretic loop (W_d) and the stored energy in an elastic material having the same E as the viscoelastic material (W_s), as illustrated in Fig. 1.
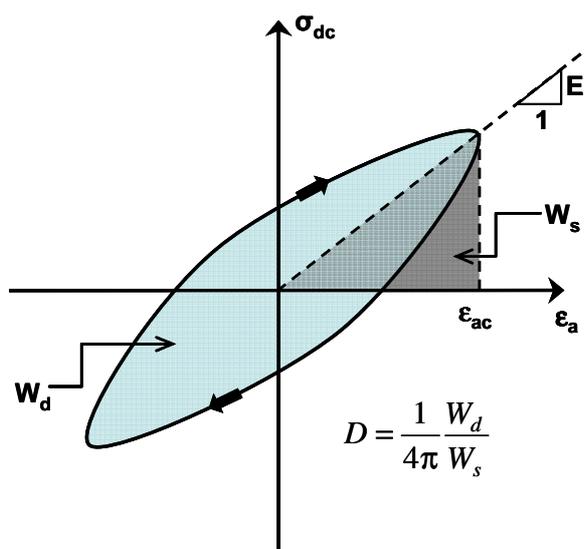

$$D = \frac{1}{4\pi} \frac{W_d}{W_s}$$

Figure 1. Schematic of a cyclic stress-strain hysteresis loop for a viscoelastic material and corresponding Young's modulus (E) and energy quantities (W_s, W_d) used in damping ratio (D) calculations.

Figure 2 shows trends of variation in measured dynamic viscoelastic properties, i.e., normalized Young's modulus (E/E_0) and damping ratio (D), of EPS geofoam at various cyclic axial strain amplitudes (ε_{ac}) for various initial deviator stress levels. The initial Young's modulus, E_0, used to derive the normalized modulus values represents the E value corresponding to a cyclic axial strain amplitude ε_{ac} = 0.01% and was obtained from regression analysis conducted for each series of cyclic uniaxial tests associated with a specific static deviator stress level. The normalized modulus curve appears to be sensitive to the static deviator stress (σ_{ds}), displaying a more pronounced decay at smaller static deviator stress levels (Fig. 2). On the other hand, no clear influence of the static deviator stress on measured damping ratio (D) could be discerned.

Overall, D shows a decreasing trend with increasing cyclic axial strain amplitude. This phenomenon is well illustrated by the results in Fig. 3 showing at larger cyclic axial strain amplitude a reduction in the breadth of the hysteresis loops (i.e., dissipated energy W_d in Fig. 1) relative to the stored elastic energy W_s (Fig. 1), both W_d and W_s quantities being present in the damping ratio equation (Fig. 1). Measured damping ratio values for EPS25 in these cyclic uniaxial tests ranged within 1.3-3.3%.
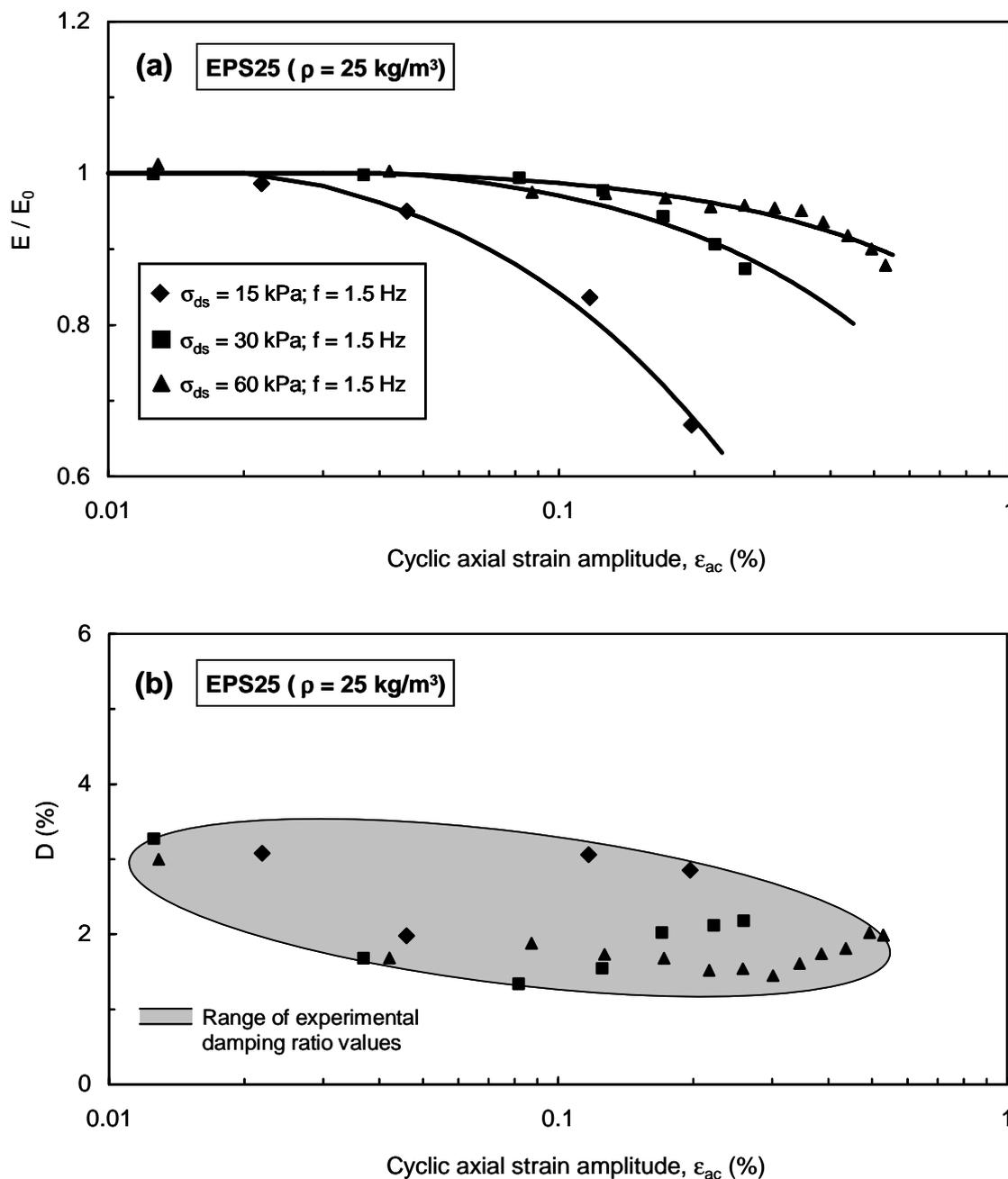

Figure 2. (a) Normalized Young's modulus (E/E_0) and (b) damping ratio (D) of EPS geofoam in relation to cyclic axial strain amplitude (ε_{ac}) for various static deviator stresses (σ_{ds}).
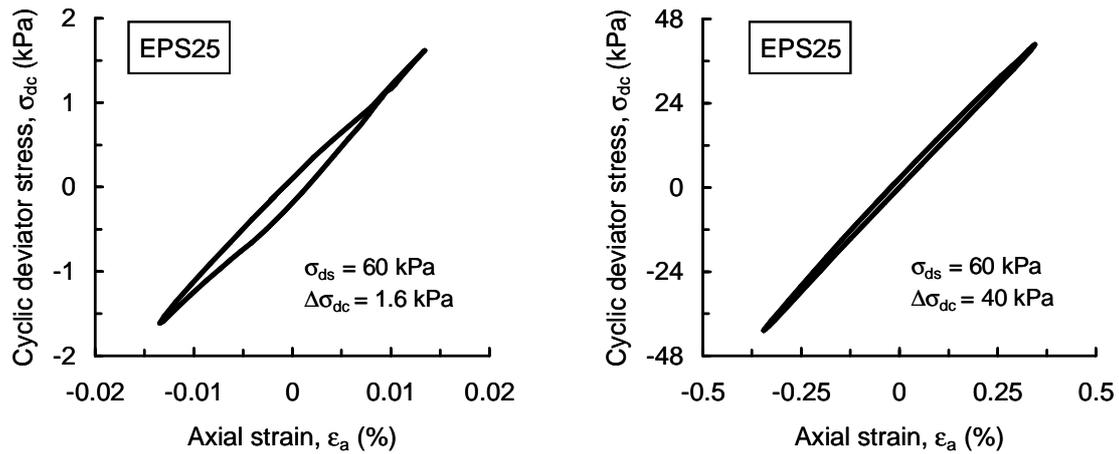
Figure 3. Viscoelastic response of EPS geofoam at different cyclic deviator stress amplitudes ($\Delta\sigma_{dc}$).

The dynamic viscoelastic properties of EPS geofoam reported in this laboratory investigation cover a range of cyclic axial strain amplitudes (ε_{ac}) up to about 0.54% (Fig. 2). For cyclic axial strain amplitudes exceeding this threshold, geofoam exhibited a visco-elasto-plastic behavior associated with plastic yielding and development of permanent strains. Figure 4 shows a representative stress-strain response characterized by plastic yielding of EPS geofoam under cyclic loading.
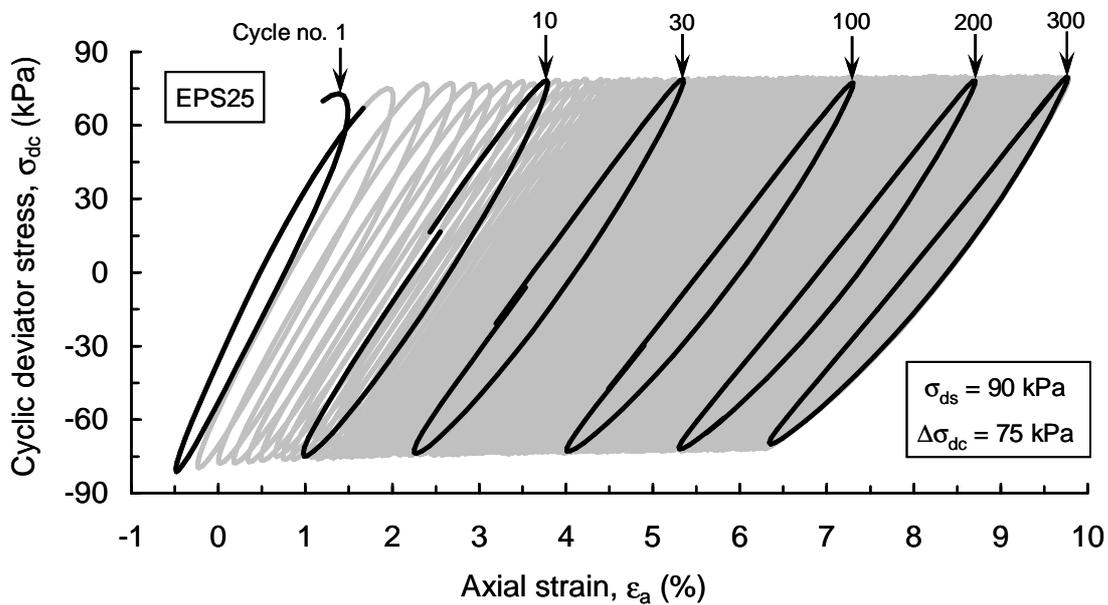

Figure 4. Plastic yielding of EPS geofoam under cyclic loading.

CONCLUSIONS

Experimental results from stress-controlled cyclic uniaxial compression tests addressing the viscoelastic stress-strain behavior of EPS geofoam indicate that the normalized Young's

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modulus degradation curve of this material is sensitive to the static deviator stress acting on the specimen prior to the application of cyclic loading. Smaller static deviator stresses are associated with steeper normalized modulus degradation curves. Conversely, the static deviator stress appears to have no influence on the measured damping ratio of EPS geofoam.

ACKNOWLEDGMENT

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