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Aurelian C. Trandafir
University of Utah, UT

Steven F. Bartlett
University of Utah, UT

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SEISMIC PERFORMANCE OF DOUBLE EPS GEOFOAM BUFFER SYSTEMS

Aurelian C. Trandafir
Department of Geology and Geophysics
Geological Engineering Program
University of Utah, Utah-USA 84112

Steven F. Bartlett
Department of Civil and Environmental Engineering
University of Utah
Utah-USA 84112

ABSTRACT

This paper presents the results of a dynamic finite-element analysis addressing the effectiveness of a double expanded polystyrene (EPS) geofoam buffer system in reducing the peak seismic loads on a rigid, non-yielding retaining wall during an earthquake. A double EPS geofoam buffer system involves two vertical EPS panels, i.e., one EPS panel placed against the rigid wall face and another EPS panel installed at a specific distance away from the first panel in the backfill soil. Sensitivity analyses of the seismic performance of the double EPS geofoam buffer system in relation to the spacing between the EPS panels indicate that there is an optimum EPS panel spacing at which the seismic isolation efficiency of the double geofoam buffer system is maximized. Additionally, a comparative numerical study of the seismic response of double and single EPS geofoam buffers revealed that a double geofoam buffer system with an optimized EPS panel spacing is more efficient than a single panel EPS geofoam buffer for the same total thickness of EPS.

INTRODUCTION

During recent years, extensive numerical sensitivity studies employing finite-element and finite-difference approaches have been undertaken to investigate the effectiveness of expanded polystyrene (EPS) geofoam buffers in reducing the seismic earth pressures on rigid, non-yielding retaining walls (e.g., basement walls, bridge abutments, restrained walls). The results from such parametric analyses have been compiled into design charts that quantify seismic isolation efficiency as a function of geofoam buffer thickness and density, wall height, dynamic stress-strain properties of the retained soil mass, and characteristics of the base input excitation (e.g., Pelekis et al., 2000; Hazarika 2001; Hazarika and Okuzono, 2002, 2004; Zarnani and Bathurst 2005, 2006; Athanasopoulos et al., 2007; Zarnani and Bathurst, 2009). All these previous studies have focused on the seismic performance of a single vertical EPS panel installed against the rigid retaining wall.

The present investigation, however, explores the seismic performance of a double EPS geofoam buffer system. As illustrated in Fig. 1, a double geofoam buffer system may be constructed by installing two vertical EPS panels, with one EPS panel placed against the rigid wall face (i.e., EPS buffer 1) and another EPS panel installed at a specific distance, *d*, away from the first panel in the backfill soil (i.e., EPS buffer 2). The basic concept associated with a double geofoam buffer system is that the outer EPS panel (i.e., buffer 2 in Fig. 1) will function as a seismic outpost dissipating some of the strain energy induced by the earthquake in the retained soil mass before this energy reaches the inner EPS panel. The result would be an increase in the efficiency of the inner EPS panel (i.e., buffer 1 in Fig. 1).

The dynamic response of a double geofoam buffer system was investigated using the equivalent linear approach incorporated in the finite-element Quake/W module of the GeoStudio Office package (GEO-SLOPE International Ltd., 2004). For the moderate input base horizontal excitation (characterized by a peak acceleration of about 0.2*g*) considered in this study, the equivalent linear model was judged to provide acceptable predictions of the dynamic response of the analyzed geotechnical system because the stress-strain behavior of both geo-materials (i.e., soil and geofoam) is not highly nonlinear and the failure state is not reached. In addition, the equivalent linear model has also been validated against experimental results from shaking table tests on a rigid wall with single EPS geofoam buffer for peak input base accelerations not greater than 0.6*g* (Zarnani and Bathurst, 2008).

PROBLEM SPECIFICATION AND INPUT PARAMETERS

Figure 1 shows the finite-element mesh for a 9-m high retained soil mass with two EPS panels of thicknesses t_1 and

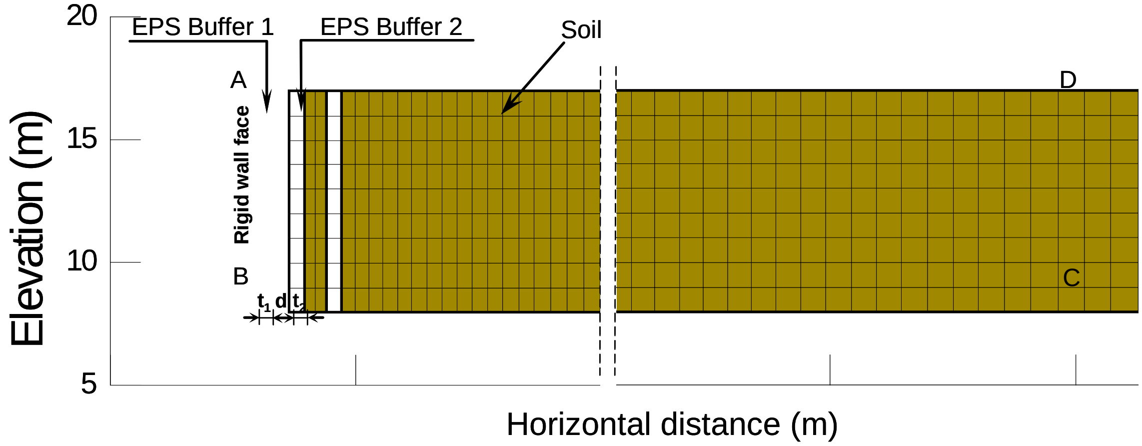


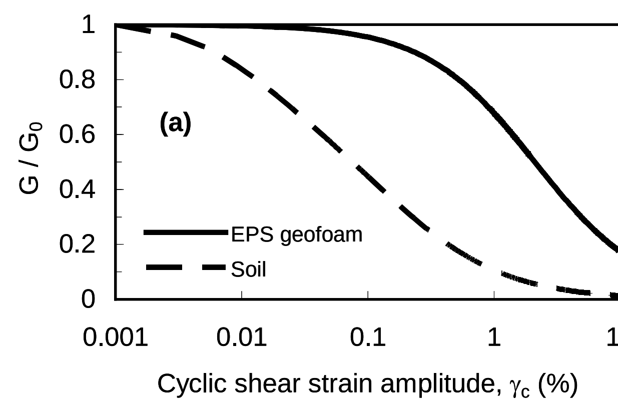
Fig. 1. Finite-element model of the retained soil mass with double EPS geofoam buffer system.

t_2, denoted as EPS buffer 1 and EPS buffer 2, respectively. EPS buffer 1 is placed against the rigid wall face, whereas EPS buffer 2 is located at a spacing *d* from EPS buffer 1 in the backfill. The boundary conditions of the finite-element model for the dynamic analysis involved restrained horizontal relative displacement boundaries along segment AB (i.e., wall face boundary), restrained relative vertical displacement boundaries along segment CD (i.e., far-field boundary) and restrained relative horizontal and vertical displacement boundaries along segment BC. The dynamic finite-element analysis employed the initial stresses obtained from a static finite-element analysis that consisted of turning on the gravitational loads in the model.

The dynamic shear modulus ratio (G/G_0) and damping ratio (D) versus cyclic shear strain amplitude (γ_c) relationships for the retained soil mass and EPS geofoam considered in the numerical study are illustrated in Fig. 2. Published equations for the dynamic properties of EPS geofoam by Athanasopoulos et al. (1999) were used to derive the geofoam relationships in Fig. 2. The soil G/G_0 and D functions (Fig. 2) were obtained using the Ishibashi and Zhang (1993) expressions for the case of a non-plastic soil subjected to an effective confining stress of 100 kPa. The initial soil shear modulus (G_0) was taken as a function of the mean static effective normal stress (σ'_m) according to the following equation (GEO-SLOPE International Ltd., 2004):

$$G_0 = K_G (\sigma'_m)^n \quad (1)$$

where K_G and n are hyperbolic fitting parameters. For the present analysis, K_G = 1874 and n = 0.5 in Eq. (1) yielding values of G_0 in kPa. A soil Poisson's ratio of 0.35 and a soil unit weight of 18 kN/m^3 were used in the analysis. An initial Young's modulus (E_0) of 8000 kPa was obtained from cyclic uniaxial tests performed in the Soil Mechanics Laboratory in the Department of Geology and Geophysics at the University of Utah. These samples were provided by ACH Foam Technologies Llc, Salt Lake City, Utah. The 50-mm diameter cylinders had a height to diameter ratio of 2:1 and a mass density of 25 kg/m^3.



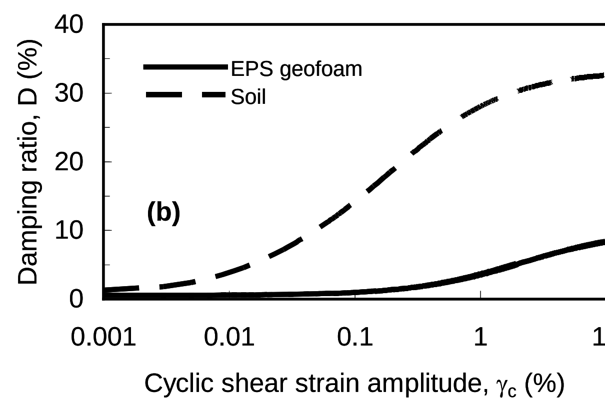


Fig. 2. (a) Dynamic shear modulus ratio versus cyclic shear strain amplitude and (b) damping ratio versus cyclic shear strain amplitude for soil and EPS geofoam.

The geofoam E_0 value of 8000 kPa obtained from the previously mentioned cyclic uniaxial tests on 25 kg/m^3 density EPS samples together with a Poisson's ratio of zero, as reported recently by investigators involved with laboratory volumetric strain measurements on EPS geofoam (e.g., Atmazidis et al., 2001; Wong and Leo, 2006; Zou and Leo, 1998), were employed in the present numerical study.

Figure 3 shows the acceleration time history of the input horizontal earthquake record that was applied as base excitation along the segment BC of the finite-element model in Fig. 1. The record is from Gilroy, California (USA) for an event that occurred on May 14, 2002, and corresponds to an epicentral distance of 2.9 km.

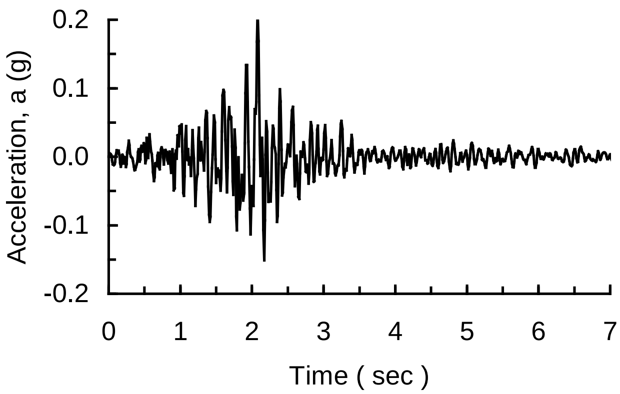


Fig. 3. Input horizontal seismic excitation.

COMPUTATIONAL RESULTS

The seismic performance of the double EPS buffer system was evaluated for the above record in terms of the attenuation of the peak dynamic wall thrust for various individual thicknesses (t_1 = t_2) and spacing (d) of the two EPS panels composing the system. Furthermore, a numerical investigation addressing the seismic isolation efficiency of the double EPS buffer system in comparison with a single rectangular EPS buffer having the same thickness as the total thickness of the double EPS buffer system (i.e., $t_1 + t_2$) was considered.

Figure 4 shows the computed time histories of the dynamic component of the wall thrust (per unit length of wall) for the case of a rigid wall with no EPS buffer, rigid wall with a single rectangular EPS buffer 120 cm thick, and rigid wall with a double EPS buffer system involving two EPS panels with individual thicknesses of 60 cm (yielding a total EPS thickness $t_1 + t_2$ = 120 cm) and a spacing of 90 cm. The time history of the dynamic wall thrust was obtained by integrating the finite-element computed dynamic component of the horizontal stresses across the wall height during the earthquake. The model suggests that both EPS buffer systems reduce the peak dynamic wall thrust when compared with the rigid wall case without an EPS buffer. However, the double EPS buffer system appears to be somewhat more effective than a single EPS buffer. For the same total EPS thickness (i.e., 120 cm), the double EPS buffer system produced a greater attenuation of the peak dynamic wall thrust (i.e., down from 135.8 kN to 77 kN) compared to a single EPS buffer system (associated with a peak dynamic thrust attenuation from 135.8 kN to 83.6 kN).

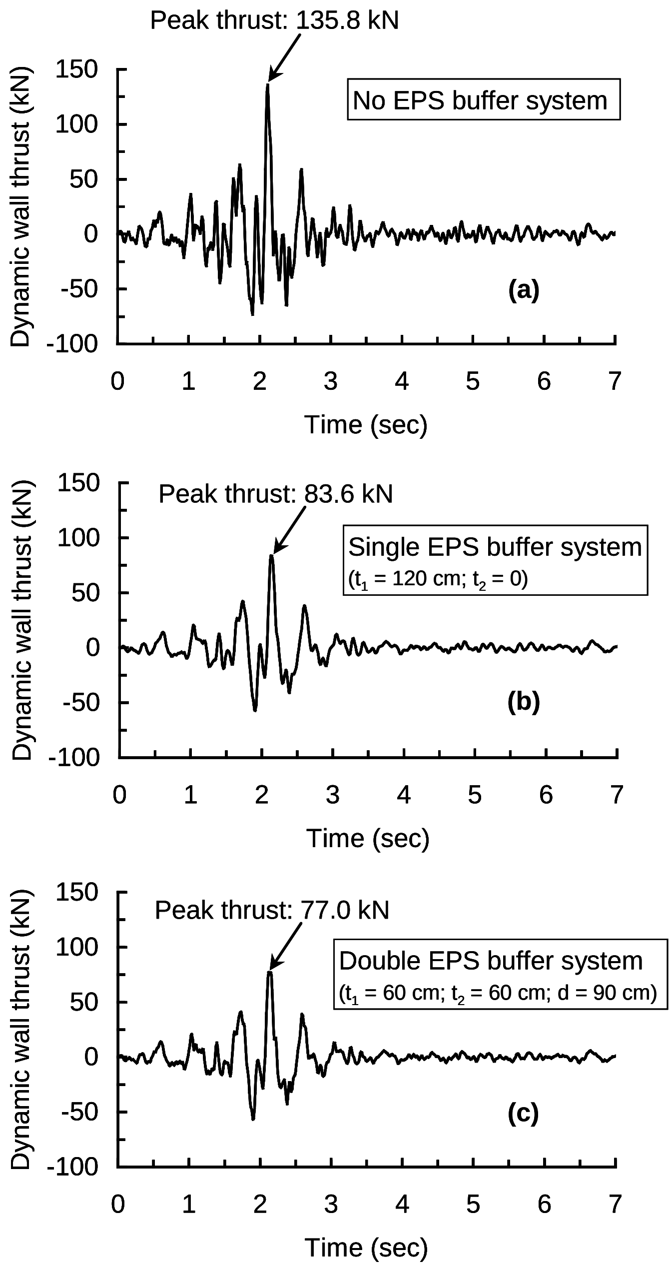


Fig. 4. Computed time histories of the dynamic component of the wall thrust for the cases of (a) rigid wall with no geofoam buffer, (b) rigid wall with single rectangular geofoam buffer, and (c) rigid wall with double geofoam buffer.

In addition, the influence of the EPS panel spacing (d) on the seismic isolation efficiency of a double EPS buffer system is illustrated in Figs. 5-7 for various individual EPS panel

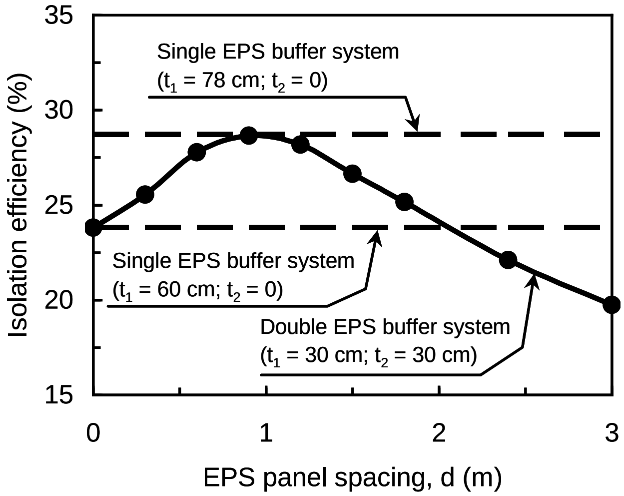


Fig. 5. Seismic isolation efficiency in relation to the EPS panel spacing for double EPS geofoam buffer system with individual EPS panel thicknesses $t_1 = t_2 = 30$ cm.

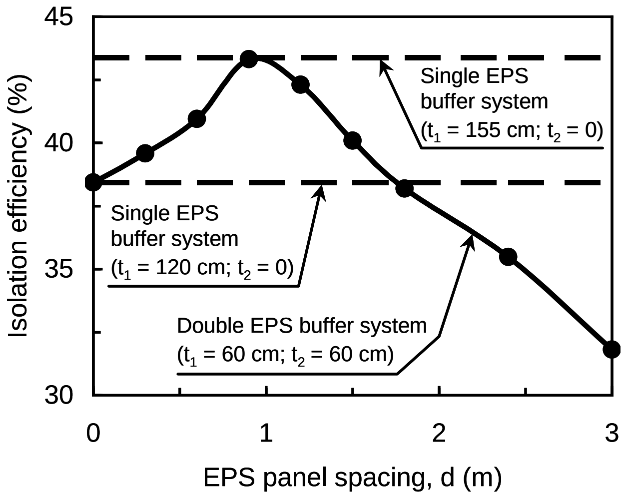


Fig. 6. Seismic isolation efficiency in relation to the EPS panel spacing for double EPS geofoam buffer system with individual EPS panel thicknesses $t_1 = t_2 = 60$ cm.

thicknesses ($t_1 = t_2$) of 30, 60 and 137.5 cm. The seismic isolation efficiency is defined as the difference between the peak dynamic thrusts on the rigid wall with no EPS buffer and on the wall with EPS buffer, divided by the value of the peak dynamic thrust on the rigid wall with no EPS buffer (Zarnani and Bathurst, 2009). The modeling suggests that in both cases the effectiveness of the double EPS buffer system increases with increasing EPS panel spacing up to an optimum distance d = 90 cm. Additional increase in the EPS panel spacing beyond this distance produces a decline in the seismic isolation efficiency of the double EPS panel system. The interpretation for this numerical outcome is that for an EPS panel spacing beyond the optimum distance, the influence of the inner soil wedge (between the two EPS panels) on the dynamic wall thrust becomes predominant, and therefore the isolation role of the outer EPS panel (i.e. EPS buffer 2 in Fig. 1) diminishes.

For the optimum spacing, the isolation efficiency of the double EPS buffer system is superior to the isolation efficiency of a single rectangular EPS buffer having the same thickness as the total EPS thickness of a double geofoam buffer. As seen in Fig. 5, the seismic isolation efficiency of a double EPS buffer system characterized by a total EPS thickness of 60 cm (i.e., individual EPS panel thicknesses $t_1 = t_2 = 30$ cm) and optimum spacing (d = 90 cm), is equal to the seismic isolation efficiency of a single EPS buffer system with a thickness of 78 cm. Likewise, the isolation efficiency of a double EPS buffer system characterized by a total EPS thickness of 120 cm (i.e., individual EPS panel thicknesses $t_1 = t_2 = 60$ cm) and optimum spacing (d = 90 cm), is the same as the seismic isolation efficiency of a single EPS buffer system with a thickness of 155 cm (Fig.6).

Figure 7 illustrates the seismic isolation efficiency of a double EPS buffer system in comparison with the efficiency of a single EPS buffer of trapezoidal and rectangular shapes. The volume of geofoam in all three buffer configurations is the same. Apparently, a single EPS buffer in trapezoidal configuration performs better than a single rectangular buffer. However, the efficiency of the single trapezoidal buffer is still slightly inferior to that of a double EPS buffer with optimum spacing (d = 90 cm).

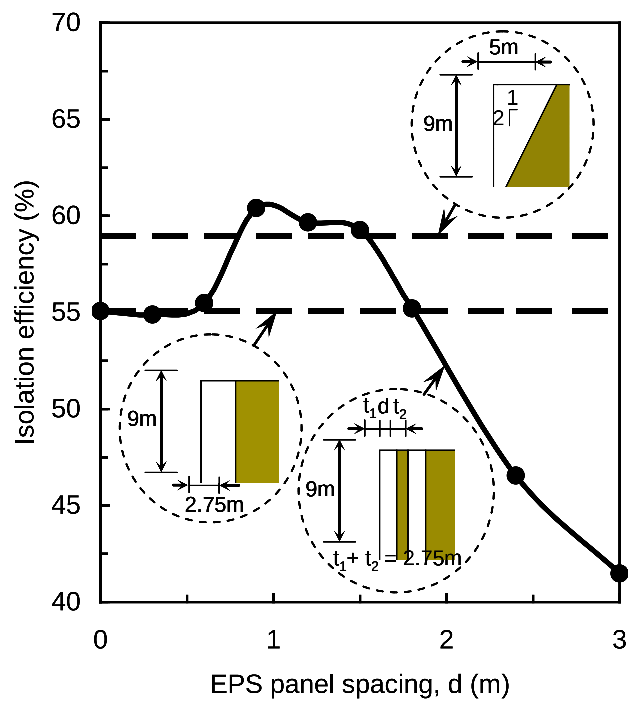


Fig. 7. Seismic isolation efficiency for various geometric configurations of the EPS geofoam buffer system of the same volume.

Figure 8 depicts the relationship between seismic isolation efficiency and total EPS thickness for a single rectangular geofoam buffer and a double EPS buffer system with optimum EPS panel spacing (i.e., d = 90 cm). For the range of investigated total EPS thicknesses, the double EPS buffer system appears to provide on average an additional 5% increase in the seismic isolation efficiency compared to a single rectangular geofoam buffer of the same EPS volume.

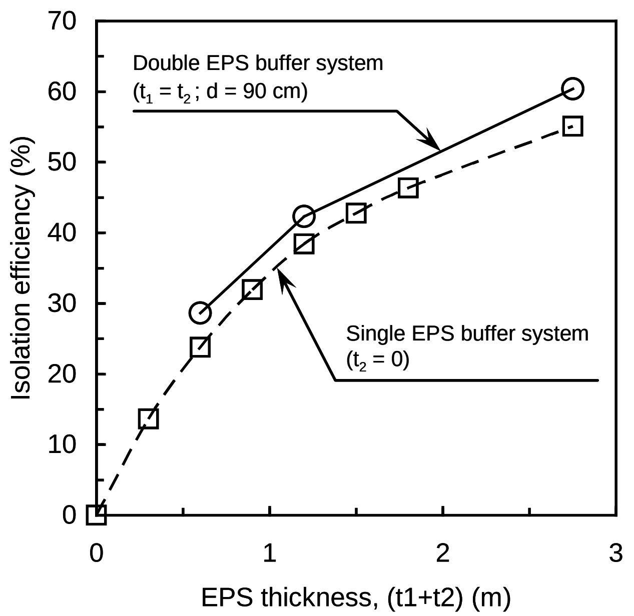


Fig. 8. Seismic isolation efficiency in relation to the total EPS thickness for single rectangular and double EPS buffer systems.

CONCLUSIONS

A dynamic finite-element analysis was conducted to investigate the effectiveness of a double expanded polystyrene (EPS) buffer system in reducing the peak seismic loads on rigid non-yielding retaining walls during an earthquake. A double EPS buffer system consists of two vertical EPS panels, and involves one EPS panel placed against the rigid wall face and another EPS panel installed at a specific distance away from the first panel in the backfill soil. The numerical results indicate that there is an optimum EPS panel spacing for which the seismic isolation efficiency of the double geofoam buffer system is maximized. A comparative analysis of the seismic performance of double and single EPS geofoam buffers revealed that in terms of isolation efficiency, a double geofoam buffer system with optimum spacing of the EPS panels is superior to a single rectangular geofoam buffer having the same thickness as the total EPS thickness of the double geofoam buffer system.

This evaluation was done using properties appropriate for EPS25 (i.e., mass density = 25 kg/m^3). Other densities of EPS will produce differing results; but in general, lower densities of EPS will produce higher isolation efficiencies because they are less stiff and hence produce a more complete compressible inclusion (Zarnani and Bathurst, 2006, 2008, 2009). For applications where the compressible inclusion undergoes plastic deformation, a more elaborate numerical scheme beyond the equivalent linear method may be warranted.

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