Seismic analysis of gravity retaining wall with EPS geofoam inclusion

Alekhya B, Subhadeep Banerjee, Boominathan. A & Krishna Chaitanya Ch
Indian Institute of Technology Madras, India

ABSTRACT: Gravity retaining walls are conventional retaining structures which have been widely used. The main objective of this paper is to study the influence of vertical inclusion of EPS (expanded polystyrene) geofoam on seismic response of gravity retaining wall. Seismic response of gravity retaining walls with and without geofoam inclusion just behind the gravity wall is investigated. A numerical model of gravity retaining wall is developed using FLAC 2D. Geofoam thickness is varied to investigate the effectiveness in mitigating seismic induced lateral wall displacements. Maximum wall lateral displacement profiles along the height of the wall are presented. From this study, it is concluded that wall with vertical inclusion of EPS geofoam performed better during earthquake motions. Increase in geofoam thickness reduces the wall lateral displacements considerably. The reduction in wall lateral displacements is found to be higher in wall subjected to low peak ground acceleration.

1 INTRODUCTION

Gravity retaining walls are traditional, rigid, earth retaining structures that retain the soil with their self-weight. High inertial forces in these walls during seismic events induce high seismic earth pressures, lateral wall displacements and wall settlements. To mitigate effects due to seismic events, several inclusions are been developed. EPS geofoam has been used in geotechnniocal enginnering due to its damping property, compression resistance, extreme light weight, durability and inertness to chemical reactions. Hotta et al (1996) observed EPS geofoam structures performed well under seismic loading.Authors also reported despite of some damage occurred to EPS sites, EPS embankments were highly stable during earthquakes in Japan. O.L. Ertugrul and A. C. Trandafir concluded that the presence of an EPS geofoam buffer provides additional reduction in dynamic earth pressure coefficients. Zarnani (2011) showed in his PhD thesis that the inclusion of a EPS geofoam layer behind the GRS wall face can reduce earth loads acting on the wall facing. Research findings conclude that expanded polystyrene (EPS) geofoam can be considered as an efficient deformable inclusion to reduce the seismic earth pressures against rigid non-yielding retaining walls.

In this study, a vertical geofoam of varied thickness is employed behind the retaining wall . The wall is subjected to acceleration histories of three earthquakes namely Umbria Marche (Italy, 1997), Montenegro (1979) and Loma Prieta, California (1989) with low, medium and high peak ground accelerations respectively. The displacement profiles without inclusion of geofoam at the wall base are compared with the results of published paper by Manya et al. (2016) and are found to be in reasonable agreement. Lateral wall displacements of the gravity wall under varying geofoam thickness and varied peak ground accelerations are presented in further sections. The lateral wall displacements profile along the height are examined.

2 MAIN STUDY

The main objective of this paper is to study the influence of vertical inclusion of EPS geofoam on seismic response of gravity retaining wall. A two dimensional numerical model is developed using FLAC 2D and same is validated against Manya et al (2016). Two types of backfill of depth 3m each are considered in this study. To investigate the effectiveness of inclusion, thickness of geofoam is varied from 0.3 to 0.9m.Walls are subjected to earthquake motions of low and high peak ground accelerations. Seismic responses of examined walls are quantified using wall lateral displacements.

2.1 *Wall description*

A gravity wall of trapezoidal shape with a height of 6m, base width of 3m and top width of 0.5m. The height of the foundation is 12.4m and the base rock height is 6.3m. The width of the model is taken as 59m. Two types of soils are used in the backfill, loose sand (Backfill 1) overlain by dense sand (Backfill 2) over the total height of the wall The thicknesses of the geofoam used are 300mm, 600mm and 900mm. The wall is vertical on the backfill side and inclined to 67^0 with the horizontal on the other side.

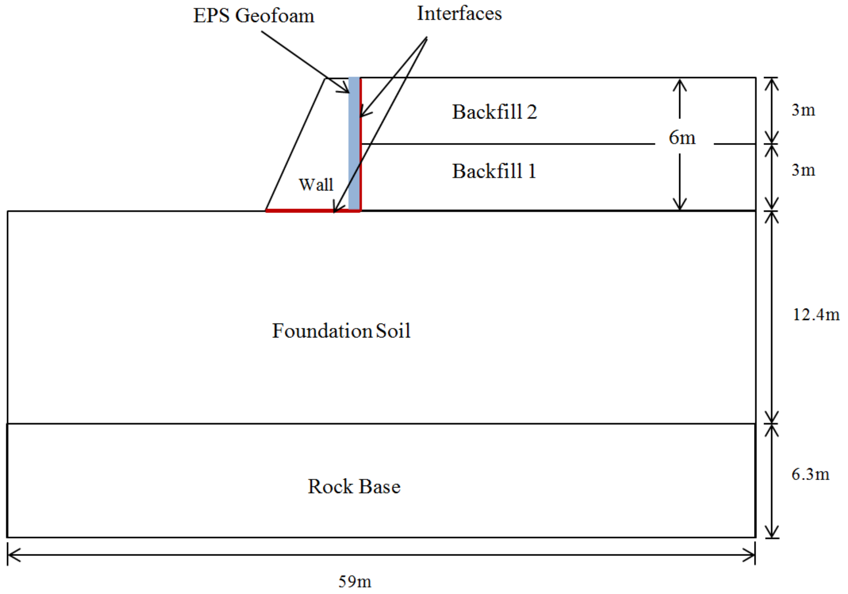


Figure 1. Schematic diagram of the model with EPS inclusion

2.2 *Finite difference modelling*

FLAC 2D, Fast Lagrangian Analysis of Continua 2D, is a two-dimensional explicit finite difference program for geotechnical analysis. It is preferred for dynamic analysis of retaining wall for the present study due to its better convergence compared to finite element software. Numerical model is assigned fixed boundaries for the static case and the fixities are replaced by free field boundaries at the vertical ends and quiet boundary at the base of the model for the dynamic case. The contact between the wall and soil and the wall and foundation were represented through interfaces.

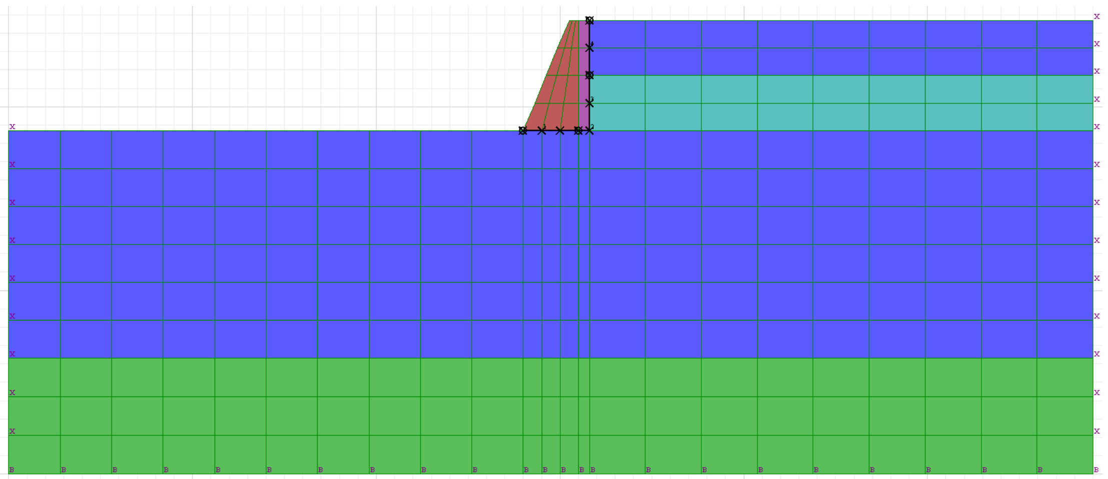


Figure 2. Meshed model in FLAC 2D

Mohr Columb failure criteria with shear strength degradation rule is assigned to soil layers. (as reported by Manya et al. 2016). To represent the modulus reduction property, the FLAC built-in "Sigmoidal 4" equivalent-linear model and Mohr-Coulomb soil model were adopted along with 5% Rayleigh damping. The base layer and the wall were modeled with linear- elastic materials. The material properties for both types of backfills,foundation soil, and the base are presented in the Table 1.The acceleration time histories of two past earthquakes with high and low peak ground accelerations are used as the input at the base of the model (Figure 5).

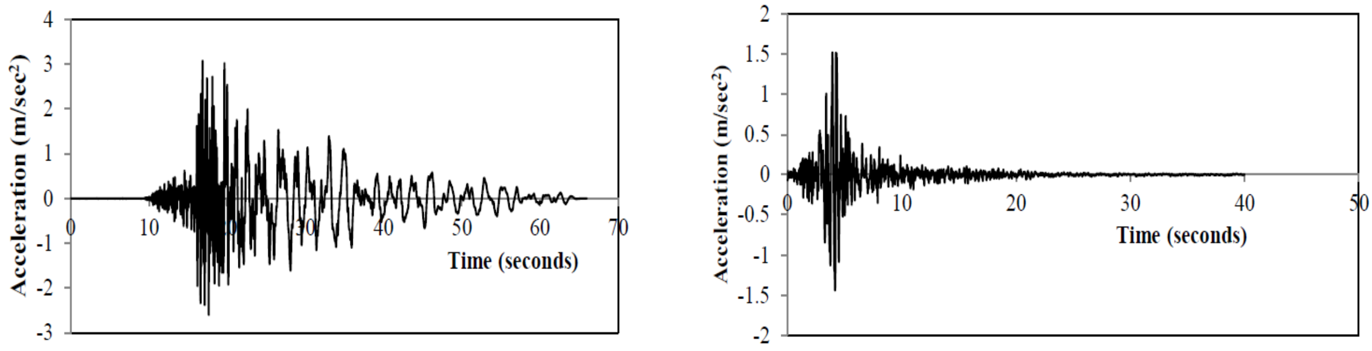
Table 1. Material Properties.

Soil type	Backfill 1 (Loose sand)	Backfill 2 and Foundation (Dense sand)	Base	Wall	EPS properties*
Void ratio	0.65	0.45	-	-	-
Mass density (kg/m^3)	1700	2000	2400	2400	16
Cohesion (kPa)	0	0	-	-	-
Friction angle (^{0})	27.5	37.5	-	-	-
Dilation angle (^{0})	5	5	-	-	-
Bulk modulus (MPa)	75.81	129.4			2.0
Shear modulus (MPa)	34.9	59.64	2000	2200	2.18
Young's modulus (MPa)	90.74	155.06	5160	5720	4.8
Poisson's Ratio, ν	0.3	0.3	0.29	0.3	0.1
Constitutive model	Mohr-Coulomb with shear degradation	Mohr-Coulomb with shear degradation	Linear elastic	Linear elastic	Linear elastic

**Reference: PhD thesis by Saman Zarnani, 2011*

Table 2. Input Earthquake details

S. No.	Name of the Earthquake	Station	M_w	PGA (g)	Scaling factor	Scaled PGA(g)	Predominant period (s)
1.	Umbria Marche, Italy 1997	Gubbio	6	0.1	3.35	0.332	0.18
2.	Montenegro, 1979	Herceg. Novi-OSD. Pavicic School	6.9	0.235	1.27	0.298	0.26
3.	Loma Prieta, California,U.S., 1989	Gilory Array 1	6.9	0.510	0.35	0.178	0.38



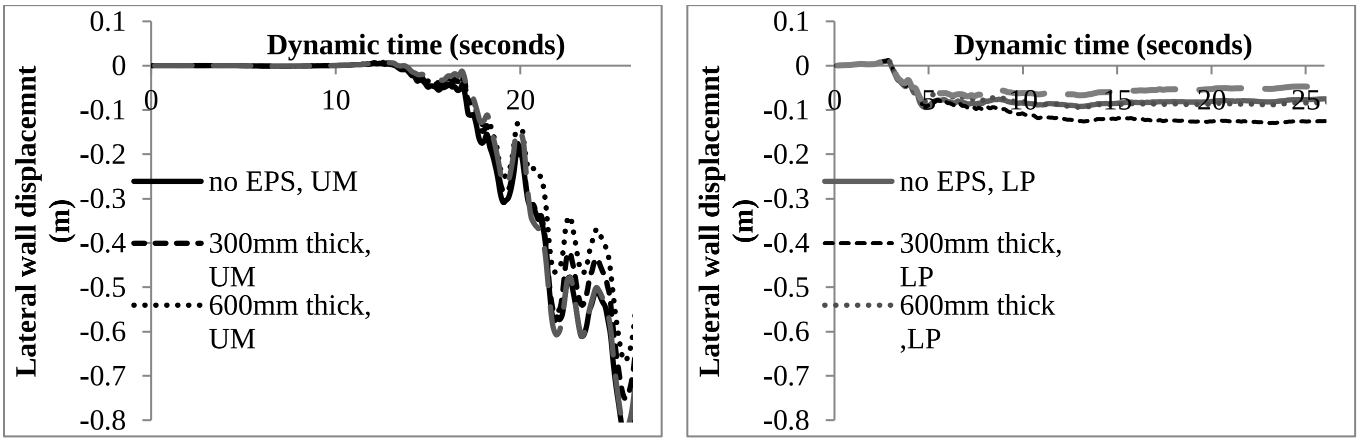
(a) Acceleration time history of Umbria Marche, Italy 1997 (b) Acceleration time history of Loma Prieta, California, U.S., 1989

Figure 3. Acceleration time histories.

3 RESULTS AND DISCUSSION

The gravity wall is analysed with two earthquake histories with peak ground acceleration of 0.100g (Umbria Marche, Italy, 1997) and 0.510g (Loma Prieta, U.S., 1989), by including geofoam of 300mm, 600mm and 900mm thickness. The lateral wall displacement profiles with dynamic time and with elevation are examined.

Peak displacements at the base of the gravity retaining wall without geofoam are found to be approximately 630mm and 100mm for the Umbria Marche, 1997 (PGA=0.1g) and Loma Prieta, 1989 (PGA=0.510g) earthquakes, respectively. Walls with geofoam inclusion performed better during seismic events. Wall lateral displacements decreased with increases geofoam thickness. It is noticed that the earthquake motion with low PGA results in higher wall lateral displacements in all cases.

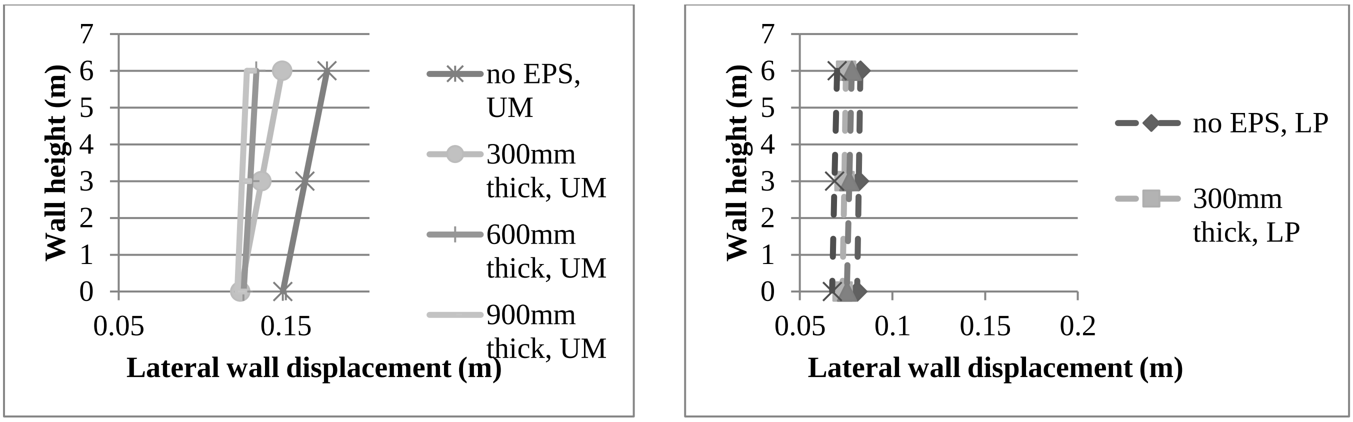


(a) (b)

Figure 4. Displacement profile at top of the wall for (a) Umbria Marche, 1997 (b) Loma Prieta, 1989

Wall lateral displacements are presented along the height of the wall for all cases. Lateral wall displacements are maximum at the top of the wall and minimum at the wall base. Lateral displacements decreased with increased geofoam thickness.

The reduction in displacements is very less for the wall subjected to earthquake of higher PGA, than that of low PGA. The reduction in displacements at wall top is about 27% for higher PGA case with thicker geofoam (900mm) and 15% for thinner geofoam (300mm). For lower PGA case, the reduction is 15% with thicker geofoam(900mm) and 9.5% for thinner geofoam (300mm).



(a) (b)

Figure 5. Displacements along the height of the wall for (a) Umbria Marche, 1997 (b) Loma Prieta, 1989

Note: UM refers to Umbria Marche and LP refers to Loma Prieta.

4 CONCLUSIONS

Gravity wall without geofoam inclusion underwent higher wall lateral displacements when subjected to both the earthquake motions (Loma Prieta, U.S., 1989 (0.510g) and Umbria Marche, Italy, 1997 (0.100g)). The inclusion of geofoam reduced the wall lateral displacements considerably, the effect being more pronounced in case of thicker geofoam. The reduction percentage in the lateral displacements of the geofoam included wall was found to be higher for the wall subjected to earthquake history with lower peak ground acceleration. Further study is required on the optimum geofoam thickness and geofoam efficiency.

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