IJCRT.ORG ISSN : 2320-2882
INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

Finite Element Analysis of retaining wall in static and seismic condition with inclusion of EPS geofoam

RIYAZ UL ISLAM, GAGANDEEP KAUR GREWAL, PRASHANT GARG, Er.SANDEEP KAUR, M-Tech Scholar, Assistant Professors , Department of civil Engineering,
GURU NANAK DEV ENGINEERING COLLEGE LUDHIANA

Abstract

This paper presents the study carried out to analyze the static and seismic behaviour of the retaining wall and backfill soil. The lateral earth pressure on retaining wall plays an important role to ensure safety of such structure. The dynamic lateral earth pressure on retaining wall during earthquake condition is always greater than static lateral earth pressure and can induce large destabilizing force. Plaxis 2D software accomplishes the analysis of retaining wall in static and seismic conditions. The retaining wall with backfill material was analysed with inclusion of compressive material EPS geofoam, which was placed at the interface of retaining wall and backfill material as an absorber to decrease lateral earth pressures on retaining wall. Parametric study of retaining wall has been done by changing various densities of EPS geofoam and thickness. This study shows that inclusion of EPS geofoam reduces the pressure on retaining wall in static as well as seismic condition.

1 INTRODUCTION

The heavy soil mass is supported by retaining walls. In the field of geotechnical engineering, retaining structures are used in highways, railways, tunnels, dams and basement of buildings etc. The soil at higher elevation would tend to move down without any structural support & it exerts pressure on the structure. The pressure exerted on structure called as lateral earth pressure. The classification of earth pressure is a function of absolute and relative movement of the backfill soil and retaining structure. If movement of wall is away from the backfill then pressure on wall known as active earth pressure and movement of wall is toward the backfill then pressure on wall known as passive earth pressure, both pressure can be computed by methods given by Coulomb (1776), and Rankine (1857) in static condition. In earthquake prone area, earthquake can induce large destabilizing force in retaining wall and backfill soil, seismically induced force has greater influence on lateral earth pressure. Mononobe-Okabe (1929) developed a method to evaluate magnitude of dynamic earth pressure based on pseudo-static approach and Seed-Whiteman (1970) suggested dynamic earth pressure can be divided into static part and dynamic part, the static part act one third of height of wall and the dynamic component of earth pressure acting at 0.6H from base, where 'H' is height of retaining wall. Wood (1973) considered the backfill is uniform and elastic; in this case, the dynamic thrust act at 0.63H.Pseudo-static approach, neglected the time effect of dynamic force, dynamic amplification and damping, Steedman and Zeng (1990) considered pseudo dynamic approach to calculate dynamic earth pressure. A new approach has been carried out by Richard-Elms (1979) based on pseudo-static displacement approach. They derived an equation to evaluate displacement of rigid retaining wall during earthquake. Whitman and Liao (1985) identified several modelling errors that result from the simplifying assumptions of Richards-Elms procedure of evaluating displacement of retaining wall during earthquake, they found that displacement were lognormal distributed (probabilistic). Variability of ground motions, uncertainty of soil properties and friction angle ' ', combining all these source of uncertainty the permanent displacement can be characterized by log normally distributed variable. In context to reduce the pressure on retaining structures the geofoam (lightweight elastic material) can be used at interface of retaining wall and backfill material. Hovarth (1997) found that the geofoam can reduce lateral earth pressure to even less those active conditions. The uniformity and compressibility of geofoam plays important role in the active and passive state of retaining wall. The total lateral earth pressure on retaining wall would decrease because some amount of pressure will dissipate to compress the geofoam. Bathurst et al. (2001) investigated the performance of seismic geofoam buffers by carrying out physical shaking table tests on 1-m high non-yielding rigid wall with granular backfill and found a maximum dynamic force reduction found up to 31%.

2 MATERIALS & METHODS

2.1 Properties of sand

The backfill material is considered as cohesionless soil (sand). The specific gravity of sand was 2.8, the void ratio at loose state was 0.82 and dense state (e_{min}) was 0.48. The mechanical properties of sand was computed in laboratoryby Bender Element Test.This laboratory test is based on wave propagation through soil sample. It consist of source element and receiver element arranged in triaxial cell base. When high frequency electrical pulse is applied to source element it produces a stress wave that travel through the specimen toward the receiver element, it generate a voltage pulse which is measured by receiver element. Shear waves and primary wave will generate due to high frequency electrical pulse, which is applied to source element by producing a stress wave. The piezo ceramic bender element is an electro-mechanical transducer, which is capable of converting mechanical energy to electrical energy. Shear wave and primary wave velocity determination in sands is important parameter for analysing and predicting safety of various structures located on it. The small strain shear modulus of soil is a fundamental parameter used in various kinds of geotechnical analysis especially in earthquake geotechnical engineering and soil dynamics.For this test, the sample length was taken of height 12 cm and the diameter was 6.0 cm. These dimensions were selected to obtain the best results from bender element tests because a slenderness ratio is two or greater than 2 gives the best results(Camacho-Tauta, 2012). In this test, the p-wave and s-wave velocity (Figure 1 and Figure 2) are computed by dividing the length of the sample by the time taken by waves to movefrom the source end to the receiver end.Table 1 shows results of this test at different densities of sand.

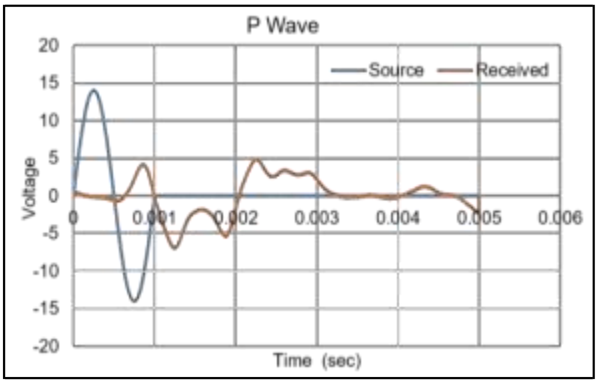

Figure 1. Bender element test result for P-wave of sand at 16.5 kN/m^3 density.

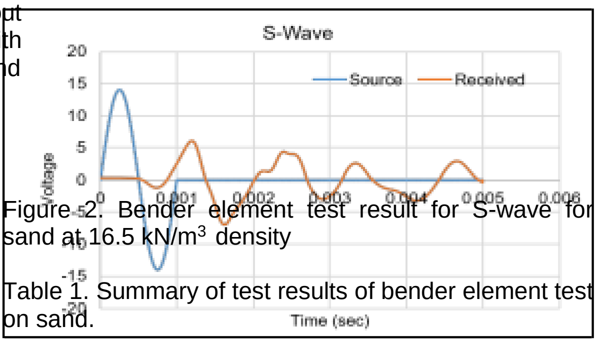

Figure 2. Bender element test result for S-wave for sand at 16.5 kN/m^3 density

Table 1. Summary of test results of bender element test on sand.

Density (kN/m^3)	Wave Type	Velocity (m/s)	υ	E (kN/m^2)
15.5	P-wave	153	0.29	27453
	S-wave	83		
16.5	P-wave	179	0.30	38973
	S-wave	95		
17.5	P-wave	194	0.30	48923
	S-wave	104		

2.2 Properties of Geofoam (Extruded Polystyrene)

In textile term, the geofoam is called as Expended Polystyrene (EPS). The geofoam is a super light material which is available in the form of blocks. As per ASTM D 4439 the density varies from 11 kg/m^3 to 40 kg/m^3. It is very much compatible with conventional construction materials such as concrete and steel. The compressible inclusion at the interphase of backfill and retaining wall.

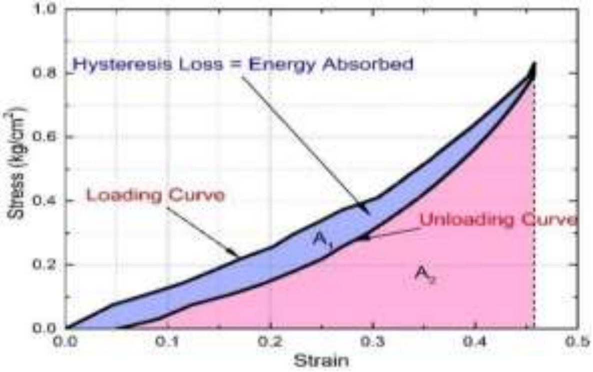

Figure 3. Hysteresis loss in Geofoam

The hysteresis loss of energy in the foam was calculated according to ASTM D 3574–17 to determine damping of energy (Figure 3). Thecompression force displacement (CFD) procedure was followed. The hysteresis loss and for used EPS foam it is 25%.The behaviour of EPS geofoam under compression test is affected much due to its density (figure 4). Higher the density, higher is the compressive strength. In initial linear response of curve, the stress-strain behaviour of EPS geofoam is almost linear up to 1.5% of strain level and reaches about 80% to 85% of total compressive strength. Initial tangent modulus (E_i) is an important parameter of EPS geofoam, which characterizes the stiffness. After linear curve the non-linear stress- strain curve is called as yielding. This yielding zone is extended between strain ranges 1.5 to 5%. In zone 3 beyond the yielding, compressive stress increases marginally with increase in strain with linear variation. In present study, the specimens were tested for 15% of strain. Therefore, the zone of work hardening is limited between this range of strain.

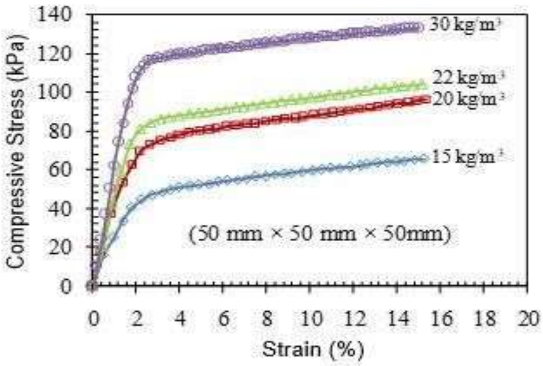

Figure 4. Stress-strain curve of geofoam

A cube of size 50mm x 50mm x 50mm was taken for compression test of different density 15 kg/m^3, 20 kg/m^3, 22 kg/m^3 and 30kg/m^3. In this paper the geofoam of density 15 kg/m^3, 20 kg/m^3 and 22 kg/m^{3}was taken for analysis and the Table 2 shows the modulus properties of respective geofoams.

Table 2. Properties of (EPS) Geofoam

Properties	Unit weight (kg/m^3)	E (kN/m^2)	υ
Geofoam 1	15	2400	0.086
Geofoam 2	20	4000	0.114
Geofoam 3	22	5000	0.170

E = Modulus of Elasticity, υ = Poisson's ratio,

3 RESULTS & ANALYSIS

3.1 Analysis of retaining wall in static condition

A retaining wall of height 6m retains sand is modelled in Plaxis 2D. It is Finite Element software, plain strain Modelling is suitable for analysis of retaining wall. Bottom of geometry is fixed while vertical movement is allowed. The material modelling for backfill sand in this software is Mohr-Coulomb model, which required modulus properties of backfill and strength parameters like angle of shearing resistance and cohesion, however strength of sand governed by angle of shearing resistance only. The material properties of sand would require for this software was evaluated in laboratory and is shown in Table 3.Plaxis works well for cohesionless soil, to avoid numerical instability while using Plaxis for cohesionlesssoil instead of taking the value of cohesion zero, it was taken 1kN/m^2.

Table 3. Properties of sand for Plaxis 2D

Properties	Unit	Value
Unit weight	kN/m^3	16.5
Young's modulus	kN/m^2	40000
Poisson's ratio	---	0.3
Cohesion	kN/m^2	1
Friction angle	Degrees	32°

The plate element is use in this software to represent retaining wall of thickness 0.85m. The retaining walls are made up of concrete. The modulus of elastic (E) for concrete (cement and aggregates) up to 50GPa (ACI 318-08). It can be also calculated according to grade of concrete according to IS-456 2000 ($E = 5000\sqrt{f_{ck}}$), where f_{ck} is characteristic compressive strength.Table 4 represent the modulus and stiffness properties of plate. Table 4.

Material Properties of Plate Properties

	Unit	Value
Axial stiffness (EA)	kN/m	4.25 x 10^6
Flexural rigidity (EI)	kNm^2/m	2.56 x 10^5
Poisson's ratio(υ)	---	0.15
Weight per area	kN/m/m	20.4

The static analysis of retaining wall includes only effect of gravity loads of backfill and retaining wall. The geometry of retaining wall with backfill is shown in figure 1, height of retaining wall plate is 6m and 2m embedded in foundation soil with 0.85m thickness (Figure 5). Backfill material was 12m extended behind the wall to show proper failure pattern in backfill.

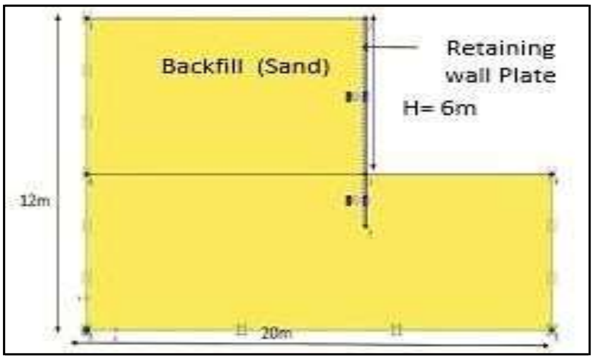

Figure 5.Geometric Model of Retaining wall and Backfill in Plaxis 2Dfor static condition

The first step of analysis was to generate the mesh formation and calculate initial stress at rest then plastic analysis was done. After completion of analysis, the output contains deformed mesh (Figure 6), and stress variation in geometry of model.

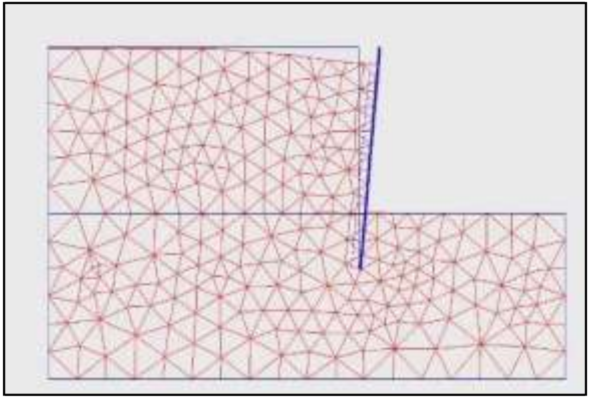

Figure 6. The deformed mesh of retaining wall and backfill after completion of static analysis.

Plaxis 2D gave maximum pressure 29.72 kN/m^2 for retaining wall of height 6m. In static condition, according to Coulomb's method, the maximum Pressure (stress) at bottom of retaining wall ($K_a \gamma H$)equals to 28.22 kN/m^2 where K_a is 0.285 and Rankine's method gave maximum pressure (stress) at bottom of retaining wall ($K_a \gamma H$)equals to 30.42 kN/m^2 where K_a is coefficient of active earth pressure equals to0.307. The value of K_a obtained by Plaxis was found 0.293. FromFigure 7 it is clear that the static lateral earth pressure on retaining wall was found apparently same, which was evaluated by Coulomb's method, Rankine's method and Plaxis 2D

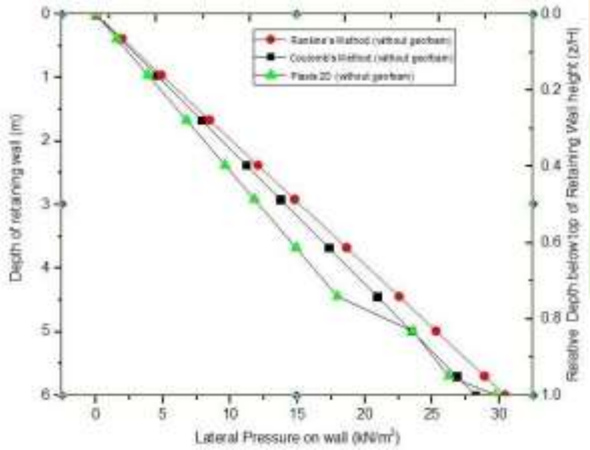

Figure 7. Lateral earth pressure on wall by different methods

3.2 Inclusion of geofoam in Retaining wall

The thick panels of geofoam of various thickness was provided at interface of retaining wall and backfill which act as absorber and reduce the pressure on retaining wall due to compressibility. Table 5 shows the various combination of thickness with different densities of geofoam been taken for analysis. 't' is the thickness of geofoam panel. The thickness to height of retaining wall ratio was taken in range of 0.085 to 0.335 for analysis.

Table 5. Various thickness of geofoam

Thickness (t) to height (H) ratio	Thickness Geofoam1 (m)	Thickness Geofoam2(m)	Thickness Geofoam3(m)
(t/H) = 0.0845	0.5	0.5	0.5
(t/H) = 0.167	1	1	1
(t/H) = 0.335	2	2	2

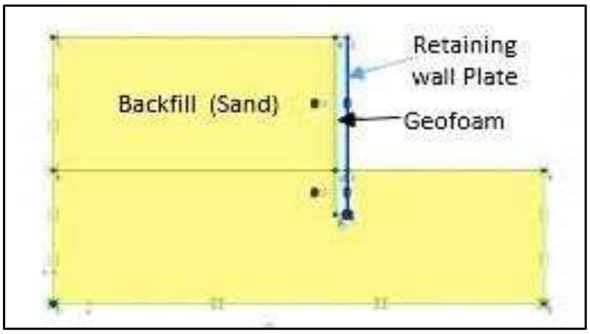

Figure 8. Retaining wall with geofoam inclusion at interface of wall and backfill in static condition

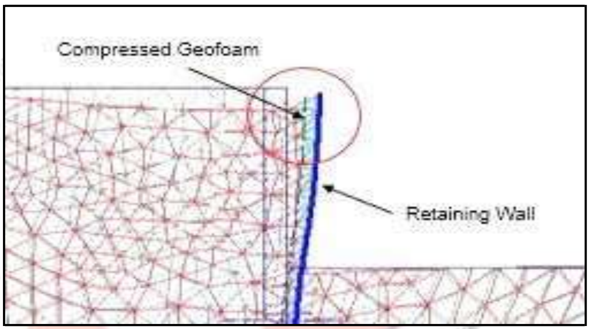

Figure 9. Deformed mesh showing compressed geofoam

Several models of retaining wall with geofoam inclusion of different densities and thickness were analysed respectivily.

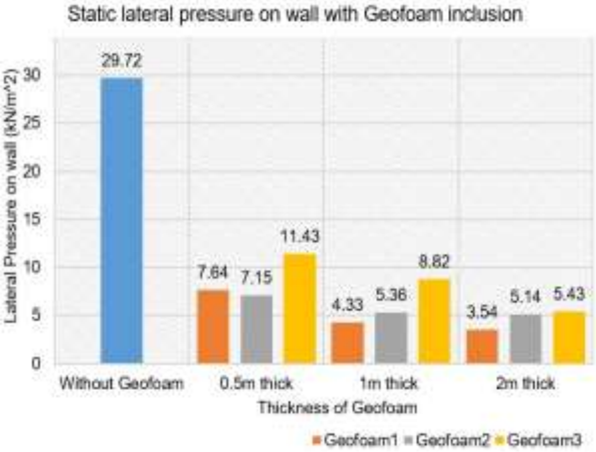

Figure 10. Static lateral earth pressure on wall with geofoam of different density and thickness.

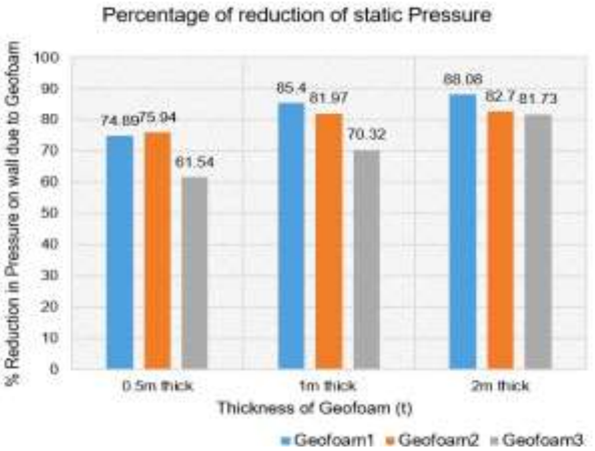

Figure 11. Percentage of reduction in static lateral earth pressure on wall with geofoam inclusion of different densities and thickness

From the above Figure 11, the average of percentage reduction in static pressure on wall by inclusion of geofoam1thickness of 0.5m is70.79%, by inclusion of geofoam2 of thickness 1m is 79.23%, and by inclusion of geofoam3 of thickness 2m is 84.17%.

3.3 Seismic analysis of retaining wall

Soil and structures are often subjected not only to static loads but also to dynamic loads. If the loads are powerful, as in earthquakes, they may cause severe damages. With this software's dynamic analysis module, we can analyse the effects of vibrations in the soil. The earthquake is modelled by imposing a prescribed displacement at the bottom boundary. At the far vertical boundaries, absorbent boundary conditions are applied to absorb outgoing waves.For plane strainmodels, the standard absorbent boundaries are generated at the left-hand, the right-handand the bottom boundary. The absorbent boundaries reduce the box effect while analysis. A real accelerogram of earthquake in standard SMC format (Strong Motion CD- ROM) given as input to Horizontal prescribed displacement to the bottom boundary shown in figure 13. The maximum Peak Ground Acceleration in this accelerogram is 0.25g.The seismic analysis of completed in two stage, first the Plastic analysis then Dynamic analysis. The time interval ofdynamic analysis is 10 seconds.

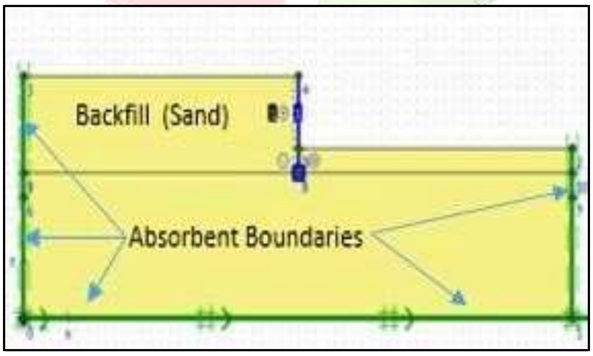

Figure 12. Geometry of retaining wall without Geofoam in Seismic condition

The mechanical properties obtained by bender element test at very small strain rate l (10^{-6} % to 10^{-5}%), the shear modulus of soil at such strain rate is a fundamental parameter used in various kinds of geotechnical analysis especially in earthquake geotechnical engineering and soil dynamics. The parameters of backfill material, Geofoams and Retaining wall plate are same as used in static condition.

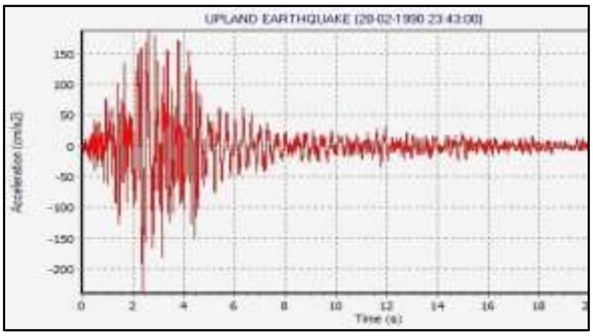

Figure 13. Input acceleration history of actual earthquake of 0.25g horizontal acceleration (in .SMC formate)

From figure 14, it is clear that that the maximum input horizontal acceleration is 0.25g gives a amplification of acceleration in backfill. The acceleration at the top of retaining wall found 0.38g while input at bottom is 0.25g, the amplification factor found 1.52 times of input horizontal acceleration.

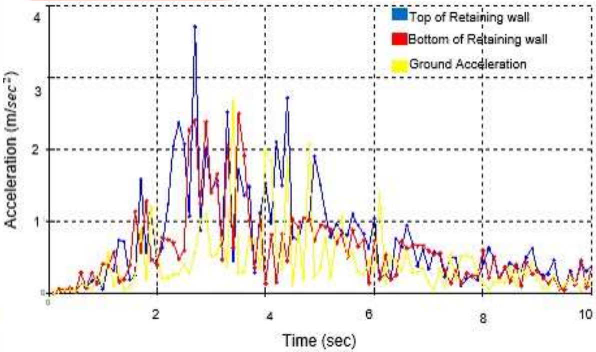

Figure 14. acceleration spectrum at top, bottom of retaining wall and Ground Level

Permanent displacement in retaining wall during earthquake can be evaluated by method of Richard- Elms (1979) and Whitman-Liao (1985) but these methods are only applicable to gravity retaining wall.

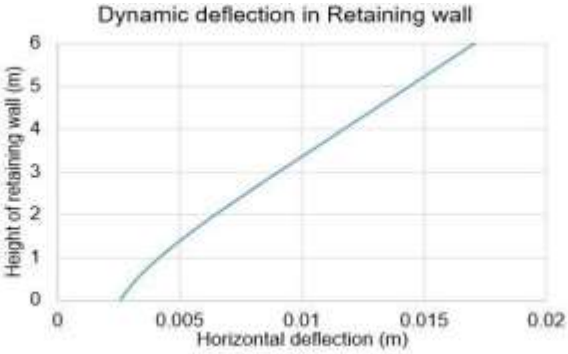

Figure 15. Permanent deflection in retaining wall

Mononobe-Okabe (1929) has developed a method to calculate dynamic earth pressure during earthquake based on pseudo-static approach that has popularly known as M-O method. This method is extension of static coulomb's wedge theory to pseudo-static condition. The dynamic earth pressure can be calculated by equation 1.

Dynamic active earth pressure (P_{AE})

$$P_{AE} = \frac{1}{2} K_{AE} \gamma H^2 (1-k_v) \qquad [1]$$

The coefficient Dynamic active earth pressure (K_{AE}) by Mononobe-Okabe method can be calculated by equation 2

$$K_{AE} = \frac{\cos^2(\emptyset-\theta-\varphi)}{\cos\varphi \cos^2\theta \cos(\delta+\theta+\varphi)\left[1+\sqrt{\frac{\sin(\delta+\emptyset)\sin(\emptyset-\beta-\varphi)}{\cos(\delta+\theta+\varphi)\cos(\beta-\theta)}}\right]^2} \qquad [2]$$

Seed-Whiteman has derived formulafor coefficient of dynamic lateral earth pressure (K_{AE}) based on the course of experiments

$$K_{AE} = k_A + {}^{3}/_{4}\, k_h \qquad [3]$$

K_A = coefficient of active earth pressure

K_{AE} = coefficient of dynamic active earth pressure

k_h = coefficient of horizontal acceleration

k_v = coefficient of vertical acceleration

P_{AE} =Dynamic active earth pressure

$\emptyset$ = Angle of shear resistance

θ = Batter angle of retaining wall

$\varphi = \tan^{-1}\left(\frac{k_h}{1 \mp k_v}\right)$

β = angle of inclination of backfill

δ = angle of friction between wall and backfill

The coefficient of dynamic earth pressure (K_{AE}) by Mononobe-Okabe method is 0.502 and by Seed-Whiteman method it is 0.456. The dynamic earth pressure found linear but Plaxis 2D shows time dependent dynamic lateral earth pressure shown in Figure 16. M-O method give maximum value of dynamic lateral earth pressure which would be safe for designing retaining wall.

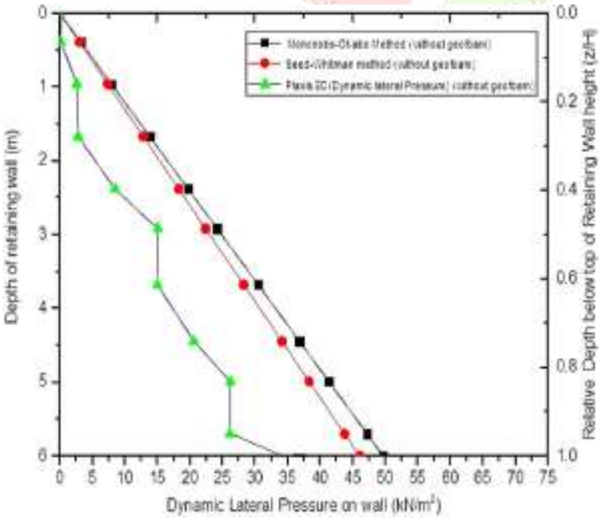

Figure 16. Dynamic earth pressure by different method

Further the dynamic analysis of retaining wall with geofoam inclusion of different densities and thickness was done and Figure 17 shows the results.

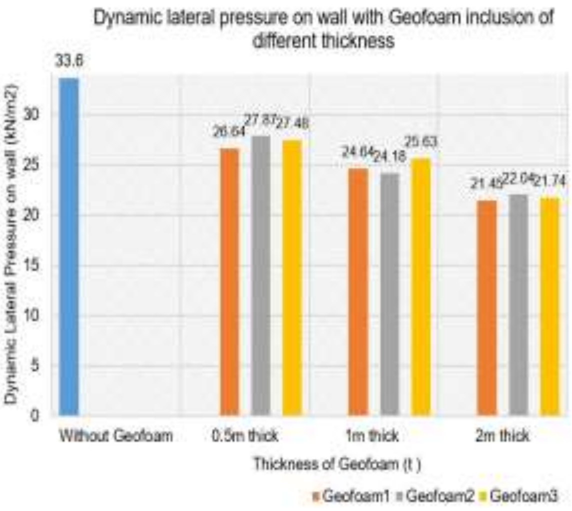

Figure 17. Dynamic earth pressure on retaining wall with geofoam of different densities and thickness

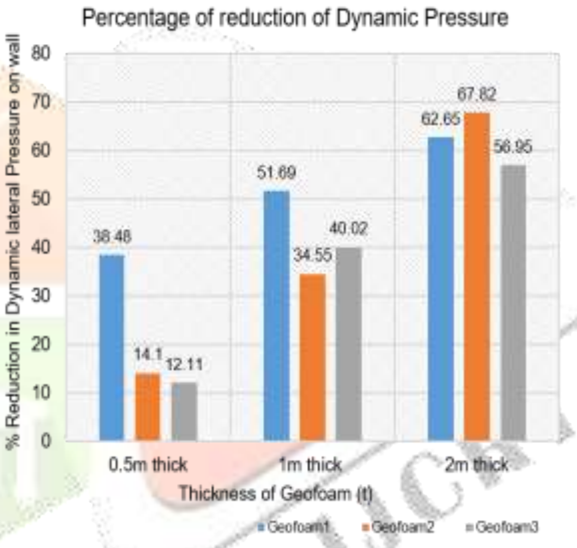

Figure 18. Percentage of dynamic earth pressure reduction by geofoam of different densities and thickness

From the above Figure 18, the average of percentage reduction in dynamic lateral pressure by inclusion of geofoam1 of thickness 0.5m is 21.58%, geofoam2 of thickness 1m is 42.08%, and geofoam3 of thickness of 2m is 62.57%.

3.4 Inclusion of geofoam in cantilever retaining wall

A cantilever retaining wall of 6m height, 3m base slab and embedded depth of retaining wall 1.65m was also modelled in Plaxis 2D shown in figure 19. The thickness of plate is 0.85m taken, first the model was analyzed without geofoam and deformed mesh is shown in Figure 20, the maximum displacement at top of cantilever retaining wall without geofoam was found 47.5mm shown in Figure 21.

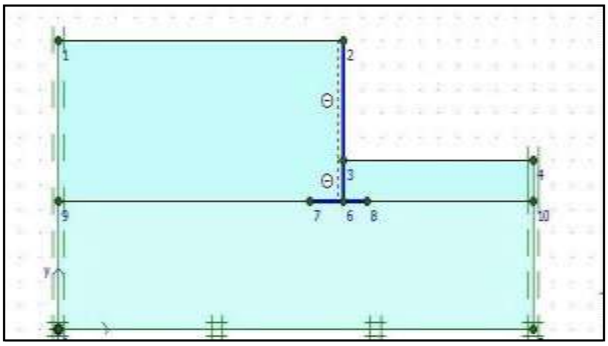

Figure 19. Geometry of cantilever retaining wall in Plaxis 2D

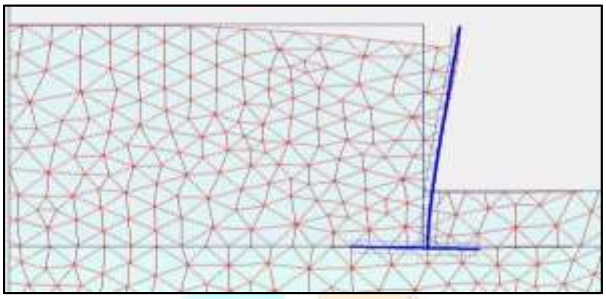

Figure 20. Deformed mesh of cantilever retaining wall system

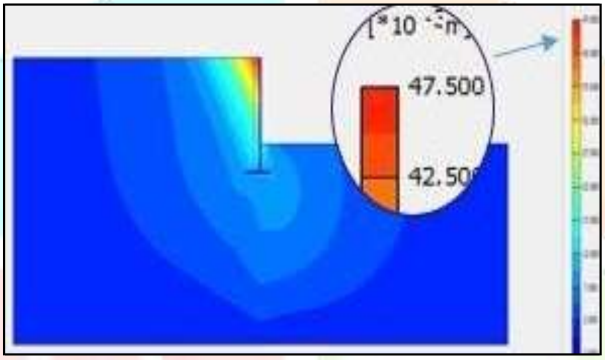

Figure 21. Horizontal displacement in cantilever retaining wall system without geofoam (mean shading).

The mean shading of horizontal stress in backfill in Figure 22 shows few plastic failure lines that can be also interpreted as triangular failure pattern taking place in backfill.

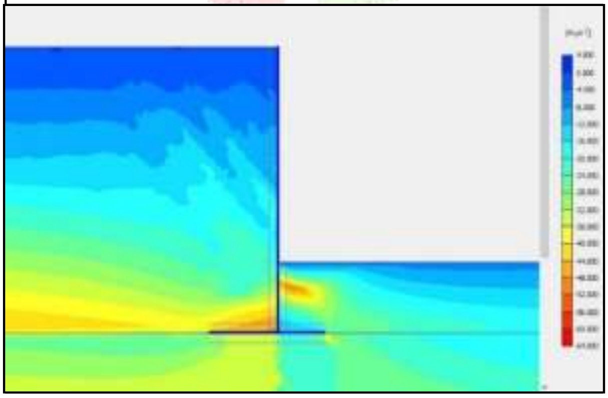

Figure 22. Mean shading of horizontal stress in backfill soilat active state of wall

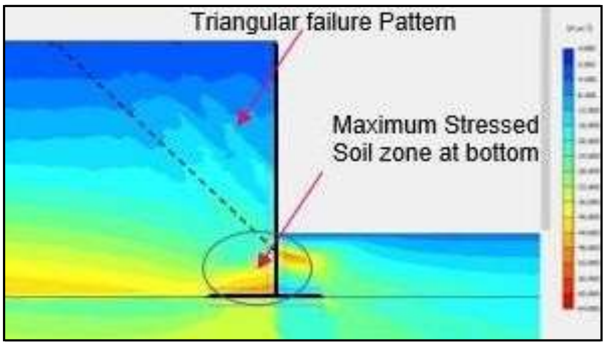

Figure 23. Interpretation from stressed soil body

From above Figure 23, it is clear that the failure zone can be trace by dotted line represent soil failure wedge and present point of application of all stress (active and passive). The lateral earth pressure is represented in in Figure 24 which give point of application of pressure. The moment on wall (stem) will be higher as compare normal generalization of lateral earth pressure.

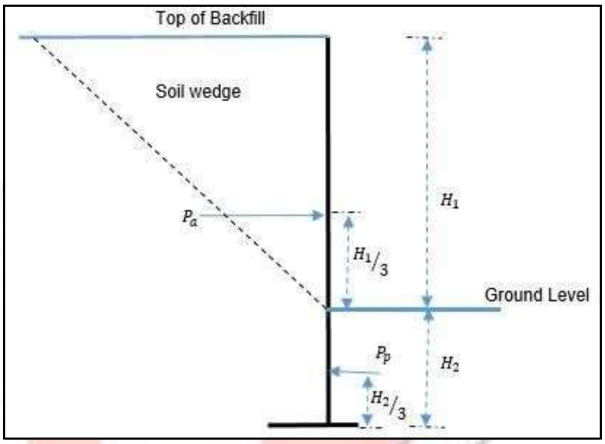

Figure 24. The point of application of earth pressure on cantilever retaining wall

In cantilever retaining wall base slab is provided, the soil above base slab increase the stability of wall. To keep this point in mind, a minimum thickness (0.5m) of geofoam is applied at interface of wall and backfill as shown in Figure 25 and analysis was done which reduces the pressure on wall as well as increase stability by reducing horizontal movement.

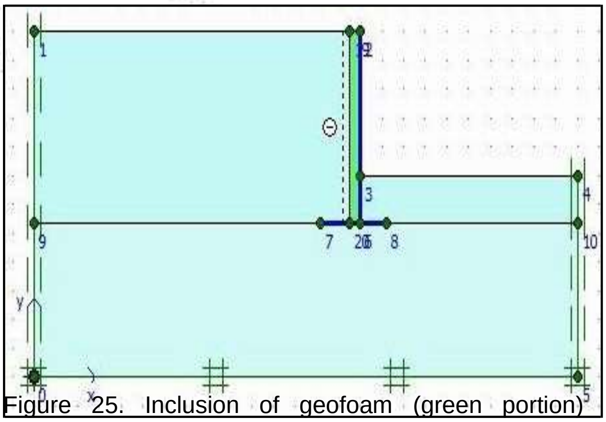

Figure 25. Inclusion of geofoam (green portion) in cantilever retaining wall at interface

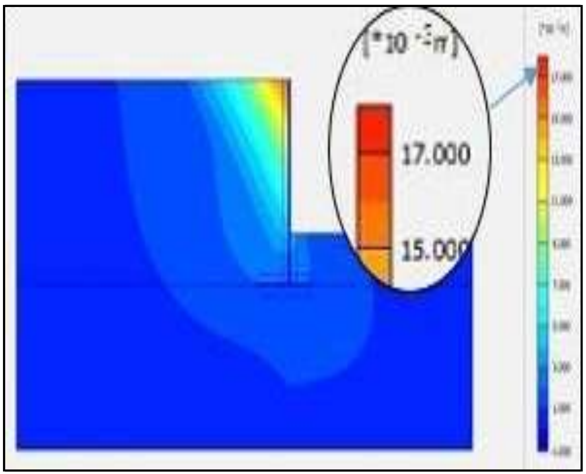

Figure 26. Mean shading Geofoam inclusion reduces lateral movement of cantilever retaining wall.

The analysis of cantilever retaining wall with inclusion of geofoam reduces the outward movement of wall, it get reduced as shown in Figure 26.

4 CONCLUSIONS

The static and seismic behaviour of retaining wall have been studied in this paper. Coulomb's method and Rankine's method used to evaluate the lateral earth pressure on retaining wall for static condition. In static condition, the Rankine method gives greater value of earth pressure than the coulombs method, which may be safe to design retaining wall. The retaining wall is modeled in Plaxis 2D to evaluate earth pressure on wall due to backfill soil in static condition and the value found similar to Coulomb's method and Rankine's Method.

In seismic condition, the M-O method is widely used method to estimate dynamic lateral earth pressure. At the conclusion of such intensive modelling of the retaining wall with geofoam as compressible inclusion at interface of backfill and retaining wall in Plaxis 2D, many observations can be made and many questions have been clarified. The major objective of this work was to reduce the pressure on retaining wall. The EPS geofoam in static condition reduces the lateral earth pressure o retaining wall up to 78.06%, and it reduces the dynamic lateral earth pressure on retaining wall up to 42.07%. As the thickness of geofoam increases the reduction in lateral pressure on retaining wall increases.

5 REFERENCES

AhmedR,2012 "Effect of Construction Sequences on the Behaviour of aBackfilled Retaining Wall" IACSIT International Journal of Engineering and Technology, Vol. 4, No. 6.

Bathurst R.J., Zarnani S., Gaskin A. 2007, "Shaking table testing of geofoam seismic buffers", Soil Dynamics Earthquake Engineering, 27 (4):324–32.

Camacho-TautaJ.,Álvarez-Jiménez J.D., Reyes-Ortiz O.J.2012,A procedure to calibrate and perform the bender element test, DYNA 79, 10–18.

GuX., YangJ., HuangM., GaoG., 2015, Bender element tests in dry and saturated sand: signal interpretation and result comparison, Soils Found. 55, 951–962,

Horvath J.S. 2010, "Lateral pressure reduction on earth- retaining structures using geofoams: correcting some misunderstandings", in proceedings ofEarth Retention Conference 3, Bellevue, Washington, ASCE GSP-208, 862–869.

Kramer S. L. 2014 "Geotechnical Earthquake Engineering"Prentice Hall, New Jersey, USA.

Kumar J., Madhusudhan B.N.2010,A note on the measurement of travel times using bender and extender elements, Soil Dynamics Earthquake Engineering 30, 630–634,

Trandafir A. C., Ertugrul O. L. 2011, Earthquake response of a gravity retaining wall with geofoam inclusion, In Proceedings of the Geo-Frontiers, ASCE GSP.211