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ACTA SCIENTIAE

ISSN: 2178-7727

DOI: 10.17648/acta.scientiae.6387

EFFECT OF TERRAIN PROFILE ON THE LATERAL EARTH PRESSURE OF DIFFERENT SOILS

Sumalatha J [1], Jyothi M. R [2], Basavanagowda G.M[3], Mahesh Kumar C L[4], Basavaraja Simpi [5], Prashant Sunagar [6*]

[1] Department of Civil Engineering, M S Ramaiah Institute of Technology, Bengaluru, 560054

[2] Department of Civil Engineering, M S Ramaiah Institute of Technology, Bengaluru, 560054

[3] Department of Civil Engineering, M S Ramaiah Institute of Technology, Bengaluru, 560054

[4] Department of Civil Engineering, Nitte Meenakshi Institute of Technology, Bengaluru 560064

[5] Assistant professor, Department of Geology, Government Engineering College, Hassan 573201

[6] Department of Civil Engineering, Sandip Institute of Technology and Research Centre, Nashik, Maharashtra, 422213, Savitribai Phule Pune University, Pune.

* *Corresponding author: Prashant Sunagar*

E-mail address: prashant.sjce@gmail.com

ABSTRACT: Unpredicted soil cave-ins in excavations and trench works are common during construction. Temporary supports are provided to prevent the collapse where the calculation of earth pressure is significant. The design of retaining walls and excavation supports depends on the earth pressure which in turn depends on the type of soil, height of the backfill, water table conditions, excavation geometry and also on the terrain profile. In the present study, it is proposed to investigate the effect of terrain profile on the lateral earth pressure of three types of soils i.e., silty sand (SM), poorly graded sand (SP) and low plasticity clay (CL). The lateral earth pressure was analyzed for the selected soils under different terrain profiles, water table conditions and earthquake forces. It was found that not only the soil type, the terrain profile is also having significant effect on the lateral earth pressure. The backfill with upward slope profiles showed higher values of earth pressure than the backfill placed at a lower level than the retaining wall. Hence, it was concluded that the terrain profile with a lower elevation than the retaining wall provides an economical design of retaining wall due to the lower value of lateral earth pressure.

KEYWORDS: Earth Pressure; Retaining Wall; Terrain; Backfill Soil; GEO5

INTRODUCTION

In the present world, the land degradation due to soil erosion and contamination has caused several problems. As land is the base for human life and its value is increasing, it is required to optimize the land resources by constructing retaining walls [1]. The buildings having basement floors requires retaining walls to support the adjacent soil and the underground tunnel shafts requires diaphragm walls which will act as retaining structure to construct the shaft. The design of retaining walls which requires the value of earth pressure needs to be estimated accurately to avoid the problems due to changes in the terrain of the backfill. Due to seasonal changes and traffic conditions, the terrain profile may change with time and hence optimum value of earth pressure should be identified by verifying the changes with respect to different terrain profiles. The earth pressure calculation is based on the properties of backfill material, water table location and the earthquake forces if any. The important properties of the backfill material that should be considered for the earth pressure analysis include unit weight, moisture content and shear strength properties. The type of soil has great significance on the earth pressure where the active earth pressure decreases with cohesion of soil and passive earth pressure increases with cohesion. The earth pressure plays a major role for designing the shoring system which is very much required to avoid the soil cave-ins in excavations and trench works. For shallow excavations, gentle slopes can be provided to avoid collapse of the soil into the trenches but for deeper excavations it is required to provide a shoring system. For clayey soils, the shoring system is not required up to a depth of critical depth which needs to be considered while designing the shoring system. As the cohesion of soil increases, the critical depth increases and active earth pressure decreases.

The critical depth (H_C) can be calculated using the equation, $H_C = \frac{4C}{\gamma} \tan \alpha$

Where 'C' is the cohesion of soil, 'γ' is the unit weight of soil and 'α' is the angle of repose.

The backfill soil is generally assumed as saturated while estimating the earth pressures to get the conservative values but in the field it may be unsaturated. The unsaturated backfill will be subjected to seasonal changes and the water content will vary due to precipitation and evaporation. The lateral earth pressure of unsaturated soil exerted on the retaining walls was studied by several researchers [2, 3, 4, 5, 6 and 7]. The three-dimensional earth pressure of active state in unsaturated soil condition was studied by [8] and [9]. The effect of soil parameters on earth pressure was studied by many researchers [10, 11, 12, 13 and 14]. The earth pressure analysis with respect to earthquake forces was studied by [15, 16, 17, 18, 19, 20, 21]. The earth pressure of a translating retaining wall and the arching effect in the backfill was studied by [22]. Fathipour et al., 2021 [23] and Mirmoazen et al., 2021 [24] studied the earth pressure due to a granular backfill with a strip footing on a geosynthetic reinforced retaining wall. They provided the design tables for earth pressure coefficients which are required to estimate the earth pressure on geosynthetic reinforced retaining walls. The industrial wastes and composite materials can be used as reinforcing material in the soil to stabilize the soil slopes [25, 26]. The use of composites as reinforcing materials for soil stabilization needs to be studied as the composites can be made of natural fibers such as jute and banana [27, 28]. The earth pressure analysis of cohesionless sand on flexible retaining walls was studied by [29, 30].

The factors influencing the lateral earth pressure are unit weight of soil, moisture conditions, shear strength parameters of the soil, angle of wall friction, surcharge and also the terrain profile of the backfill. The backfill in the field may not be always horizontal, it may have undulations and slopes where the earth pressure on the wall varies. The angle of wall friction has significant effect on the magnitude of earth pressure and the pattern of failure surface. The failure surface tends to be planar in case of smaller friction angles [31]. The calculation of earth pressure in the presence of seepage flow through the backfill was studied by [32]. There is a limited literature available on the effect of terrain profile on the lateral earth pressure. Hence, in the present study it is proposed to evaluate the lateral earth pressure corresponding to different types of terrain behind the retaining wall. As the backfill will be subjected to seasonal changes, the effect of water table was also considered for the analysis. The water table conditions varied and the results were compared. The effect of earthquake was also checked with and without water table interaction. Three types of soils i.e., low plasticity clay, silty sand and poorly graded soil were considered as backfill to estimate the earth pressure on a retaining wall of height 5 m. These soil types were selected to represent the typical soil types that are generally present behind the retaining walls. In most of the basement floor or flyover constructions, the height of the retaining wall will be between 3-7 m and hence the height of the retaining wall was selected as 5m. The variations in the lateral earth pressure were compared among the soils and different terrain profiles.

MATERIALS AND METHODS

Soils

To analyze the earth pressure of different types of granular and cohesive backfills, three types of soils namely, silty sand (SM), poorly graded sand (SP) and low plasticity clay (CL) were considered as backfill materials and the earth pressures on the retaining wall were calculated. The soil properties used for the analyses are as given in the Table 1.

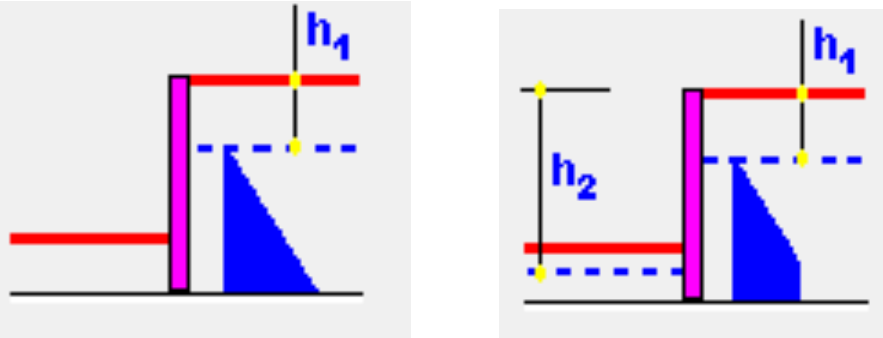
Backfill Soil	Unit weight of soil, γ (kN/m^3)	Cohesion, C (kN/m^2)	Angle of internal friction (ϕ)	Angle of wall friction (δ)
SM	18	5	29^0	12^0
SP	18.5	0	33.5^0	12^0
CL	21	12	19^0	12^0

Table 1: Backfill soil properties

Methodology

The earth pressure analysis was carried out by giving the soil properties, water table conditions, earthquake forces and terrain profile as input to GEO5 software tool and the analysis was carried out for various types of terrain profile and water table conditions. Two Ground Water Table (GWT) conditions (Figure 1) were considered to verify the effect of water table on the earth pressure. The

two water table conditions are to represent the typical locations of water table on one side and on both sides of the retaining structure which are generally present at the construction site. As a first condition (GWT condition – 1), the depth of water table on the backfill side (h_1) was taken as 1 m below the level of the backfill and as a second condition (GWT condition – 2), the water table was considered on both the sides of retaining wall where the depth of water table in front of the retaining wall (h_2) is taken as 3 m below the top of the retaining wall. Ten types of terrain profiles were studied to know the variations in the earth pressure with respect to each backfill soil type. The terrain profiles of the backfill with their geometrical properties are shown in Figure 2. Since the retaining walls constructed in earthquake prone areas may also be subjected to seismic forces, the earthquake condition was also verified with respect to the terrain profiles by taking the coefficients of horizontal and vertical accelerations. For all the analyses, the height of the retaining wall was taken as 5 m.



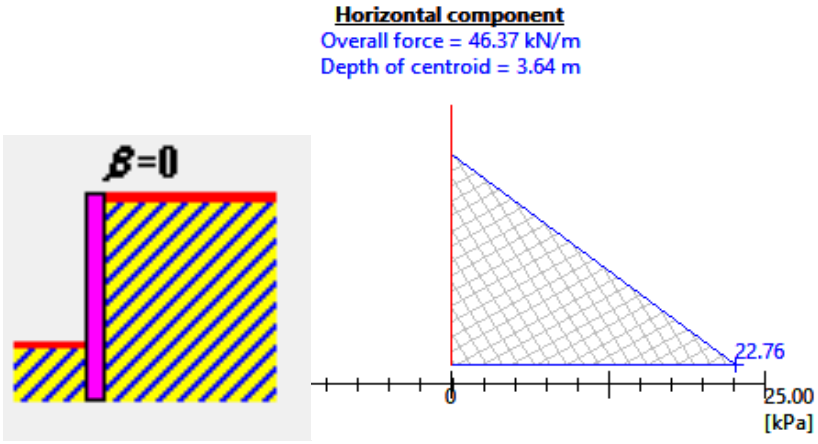
a) GWT condition – 1 b) GWT condition – 2

Figure 1. Ground water table conditions (h_1 = 1 m and h_2 = 3 m)

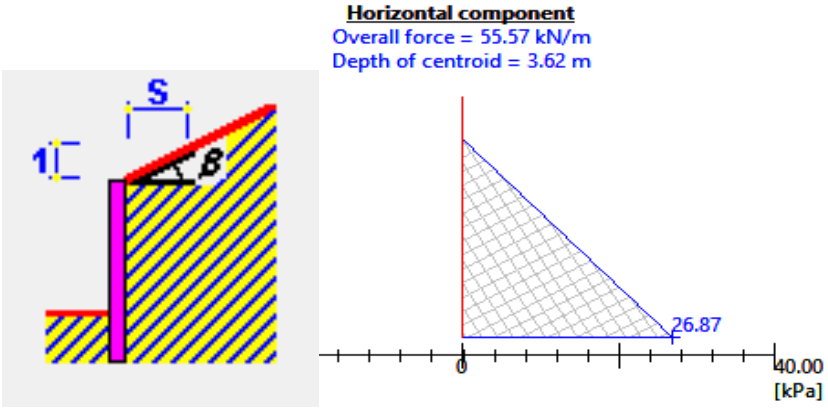
RESULTS AND DISCUSSIONS

A. Earth pressure analysis without considering the water table

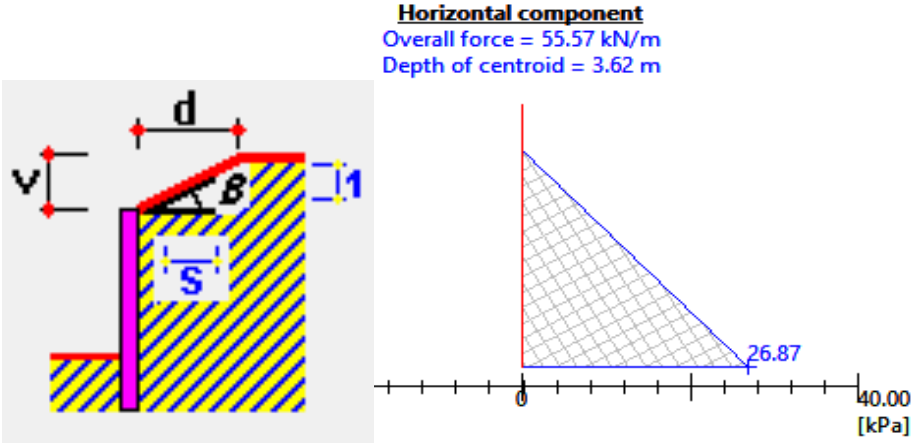
The results of earth pressure analysis with the silty sand (SM) for different terrain profiles are as shown in Figure 2. The left part of the diagram represents the backfill profile and the right part represents the earth pressure distribution and the overall force. The location of the active thrust (depth of centroid) is also obtained from the analysis. This centroid location is important to estimate the moments those are required to check the stability of retaining wall with respect to overturning, sliding and bearing capacity failure. It can be observed that the lateral earth pressure is significantly varying with the changes in terrain profile of the backfill soil. The earth pressure with the Terrain Profile – 7 is the maximum (82.39 kN/m) and with the Terrain Profile – 9, it is minimum (28.07 kN/m). It can be observed that the step-up profile of backfill (Terrain Profile – 7) is acting as surcharge and increasing the earth pressure whereas the step-down profile (Terrain Profile – 9) has reduction in the soil mass which reduced the earth pressure on the wall. The terrain profiles 2 and 3 are giving same values of earth pressure though the profile of backfill is different.



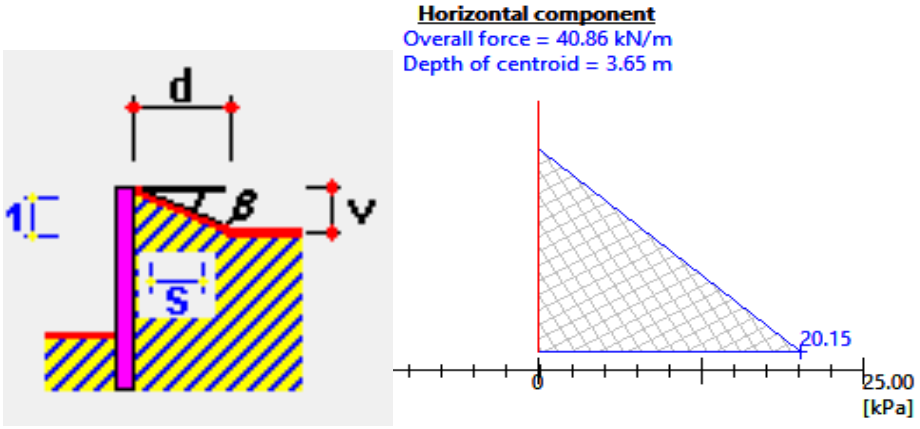
Terrain Profile – 1



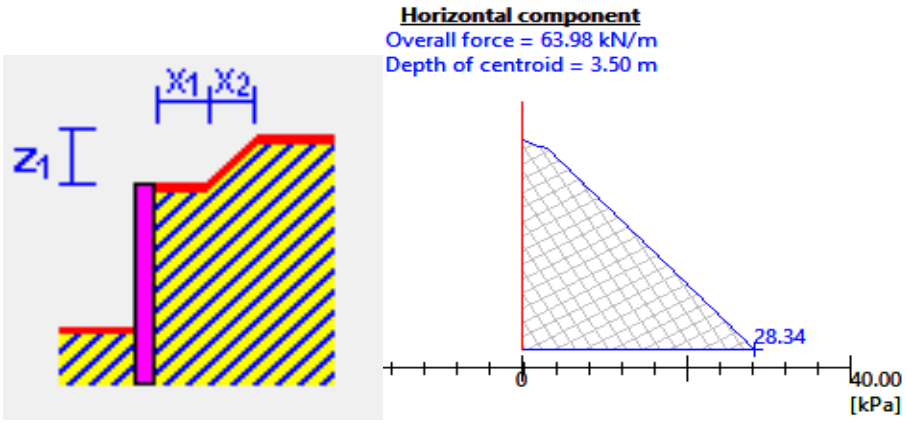
Terrain Profile – 2 (S = 5m & β = 11.30)



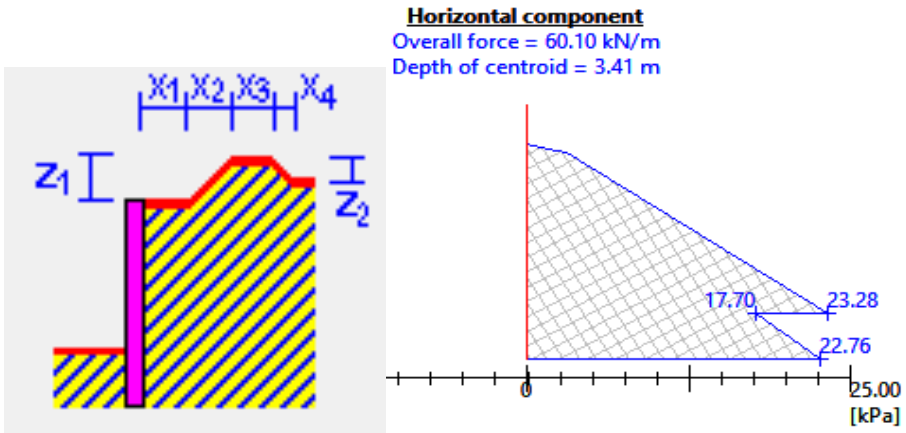
Terrain Profile – 3 (V = 1m, d = 5m, S = 5m & β = 11.3^0)



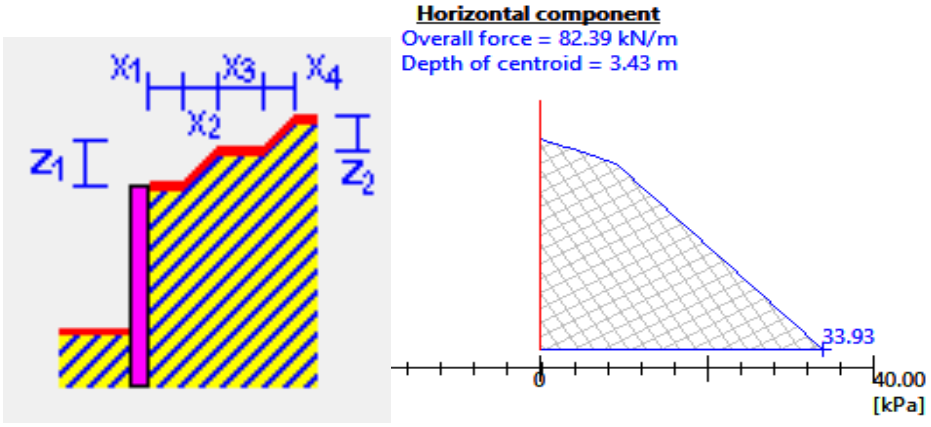
Terrain Profile – 4 (V = 1m, d = 5m, S = 5m & $\beta = 11.3^0$)



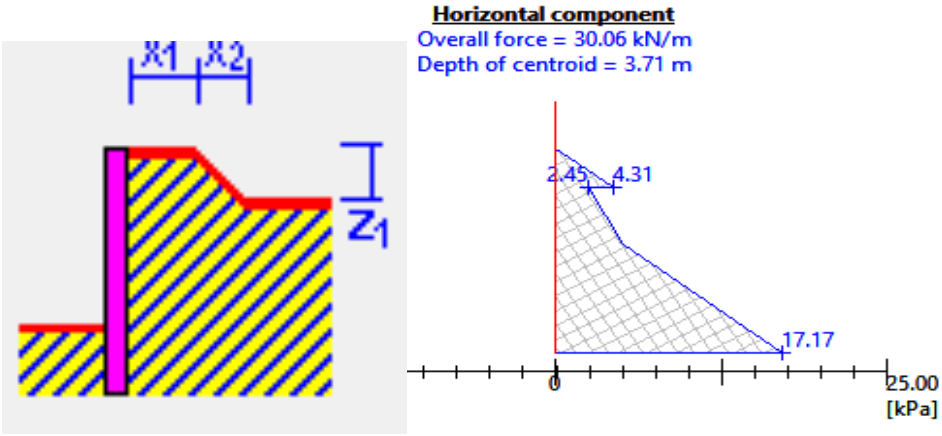
Terrain Profile – 5 (X1= 1 m, X2 = 1 m & Z1 = 1 m)



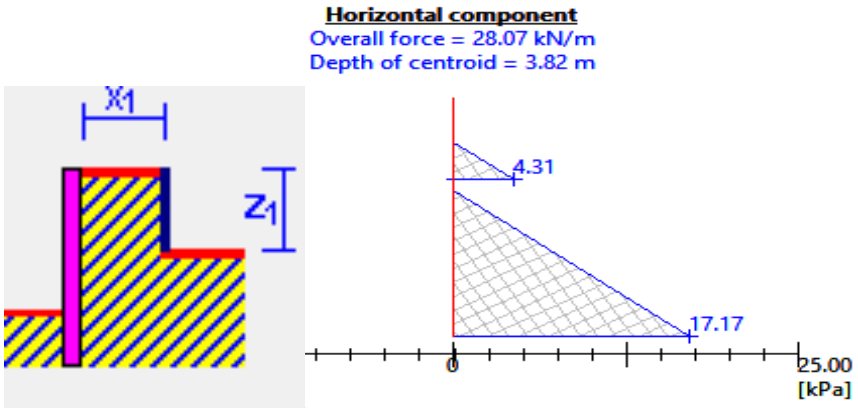
Terrain Profile – 6 ($X_1 = X_2 = X_3 = X_4 = 1$ m & $Z_1 = Z_2 = 1$ m)



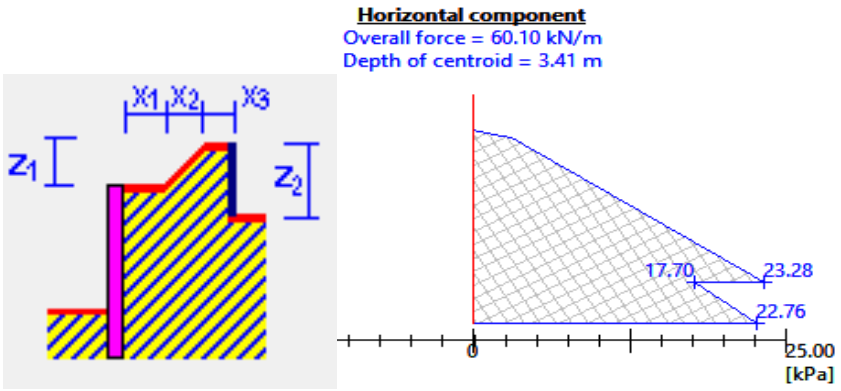
Terrain Profile – 7 (X_1= X_2 = X_3 = X_4 =1 m & Z_1 = Z_2 = 1 m)



Terrain Profile – 8 (X_1= X_2 = Z_1 =1 m)



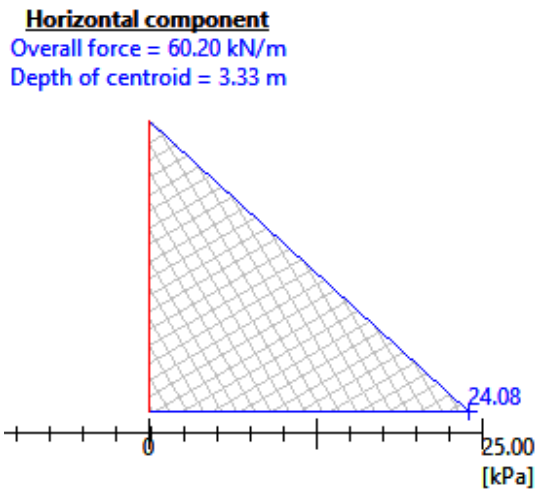
Terrain Profile – 9 (X_1= Z_1 =1 m)



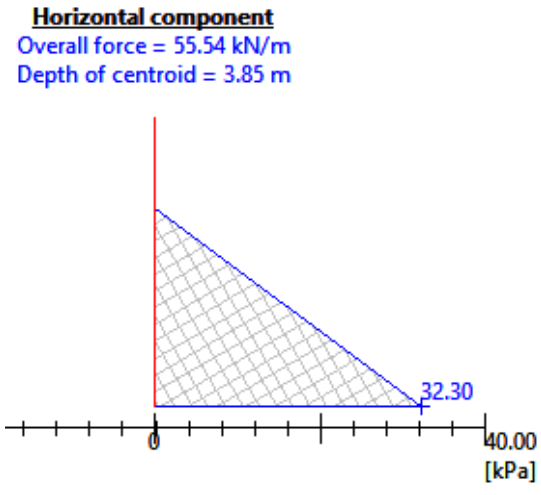
Terrain Profile – 10 (X_1= X_2 = X_3 = 1 m & Z_1 = Z_2 = 1 m)

Figure 2. Lateral earth pressure of SM with changes in Terrain Profile

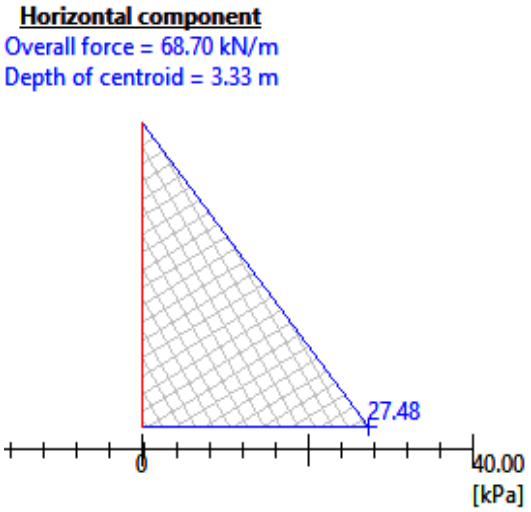
Similar analyses were conducted on the other two soils i.e., SP and CL to estimate the earth pressures with respect to the terrain profiles shown in Figure 2. The lateral earth pressures of these soils are estimated along with the overall lateral force and its location (Figure 3). From these results, it can be identified that the lateral earth pressure is relatively high with SP and CL compared to the earth pressure of SM. The earth pressure for Terrain profiles 1, 4, 8 and 9 with SP are higher than those with CL and SM. The earth pressure for Terrain profiles 2, 3, 5, 6, 7 and 10 with CL gave the maximum values when compared with SP and SM. The Terrain profile is having very significant role in the estimation of earth pressure on the retaining walls. The earth pressure is the lowest with the Terrain profile – 9 where the backfill is well below the level of retaining wall and it is maximum for the Terrain profile – 7 where the backfill is above the top of the retaining wall which is acting as surcharge. Hence, it is important to maintain a lower level of backfill behind the retaining wall which reduces the earth pressure on the wall and provides economical design of the retaining structure.



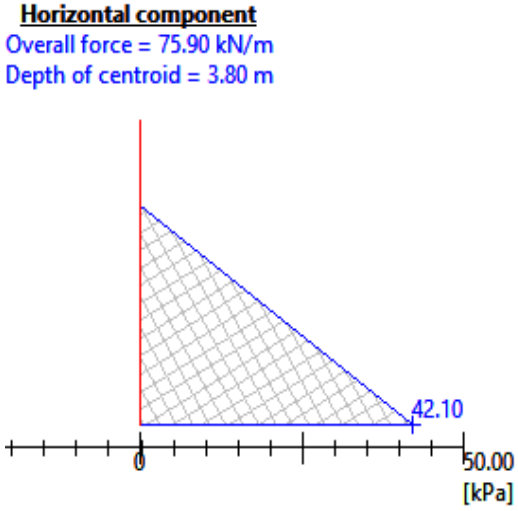
For SP with Terrain Profile – 1



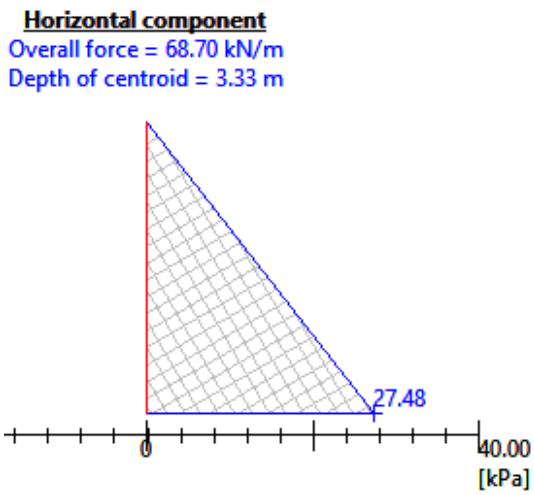
For CL with Terrain Profile - 1

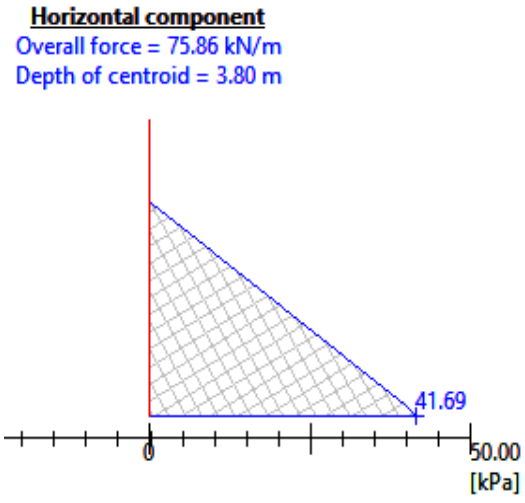


For SP with Terrain Profile – 2

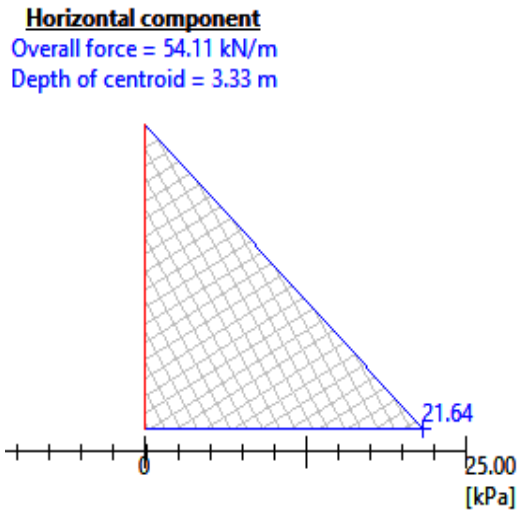


For CL with Terrain Profile – 2

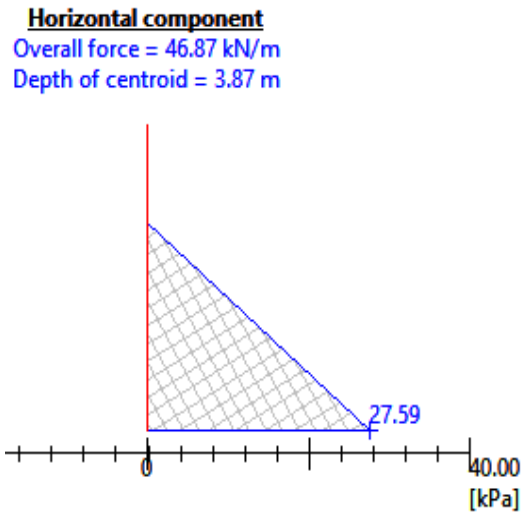




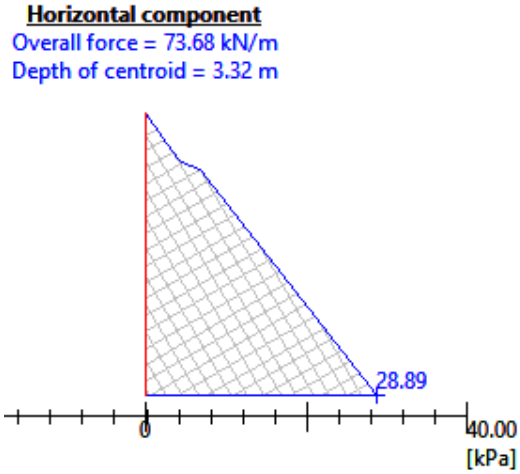
For SP with Terrain Profile – 3



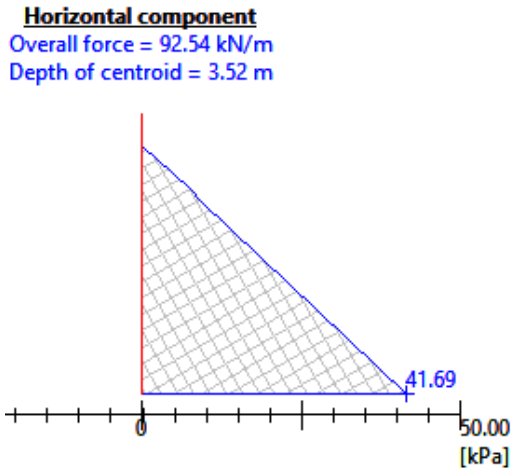
For CL with Terrain Profile – 3



For SP with Terrain Profile – 4

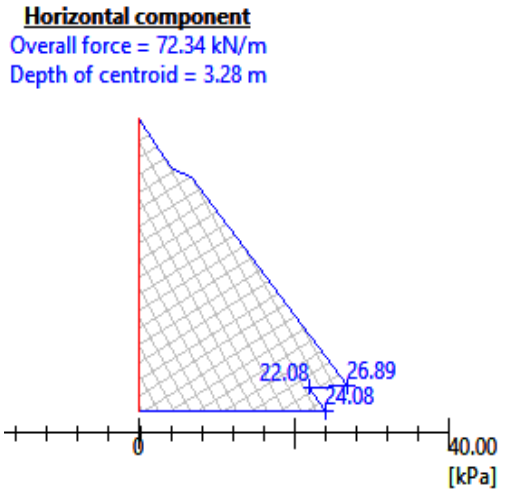


For CL with Terrain Profile – 4

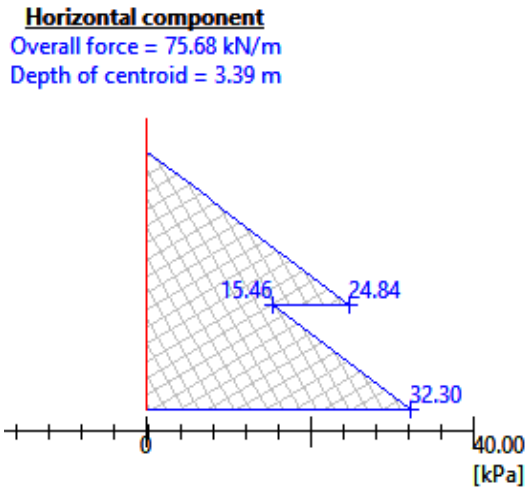


For SP with Terrain Profile – 5

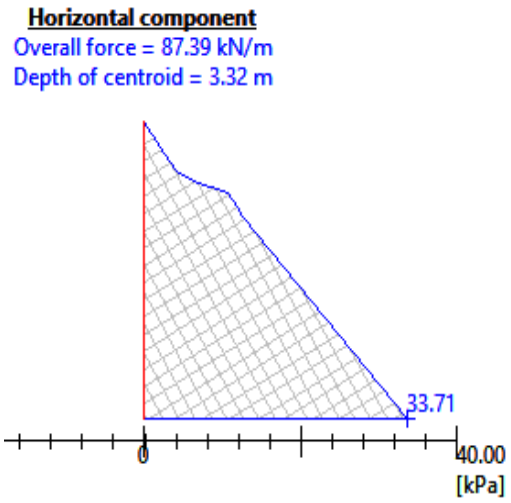
For CL with Terrain Profile – 5



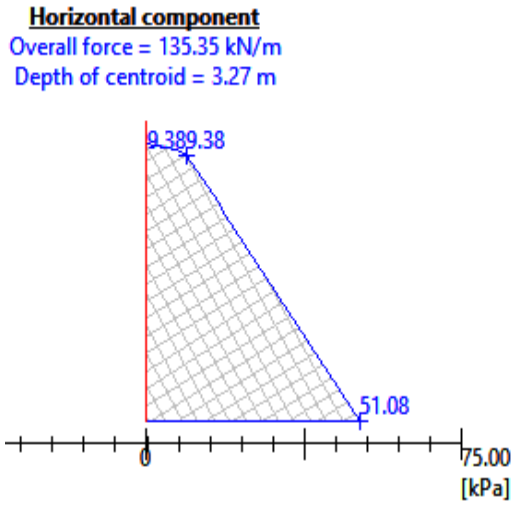
For SP with Terrain Profile – 6



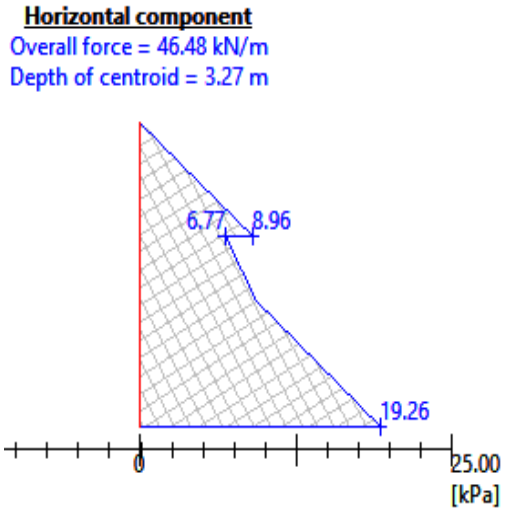
For CL with Terrain Profile – 6

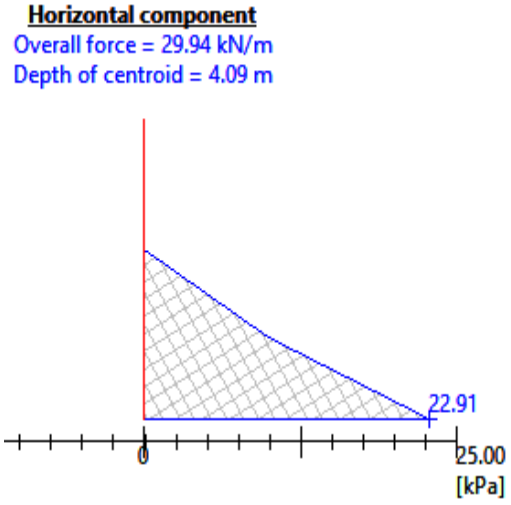


For SP with Terrain Profile – 7

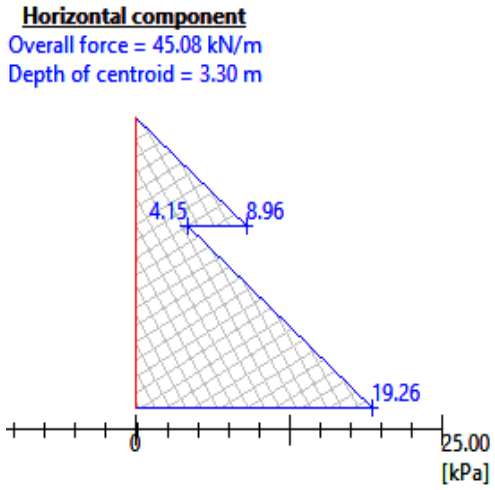


For CL with Terrain Profile – 7

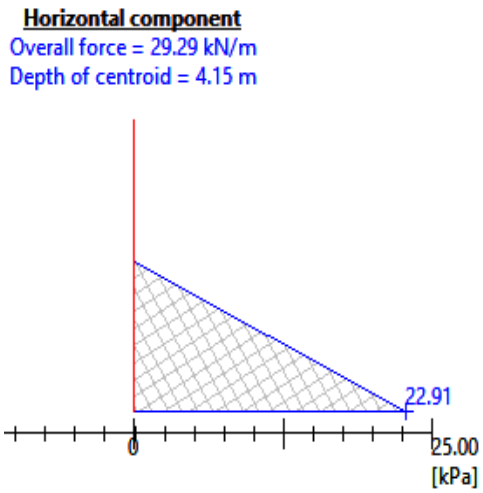




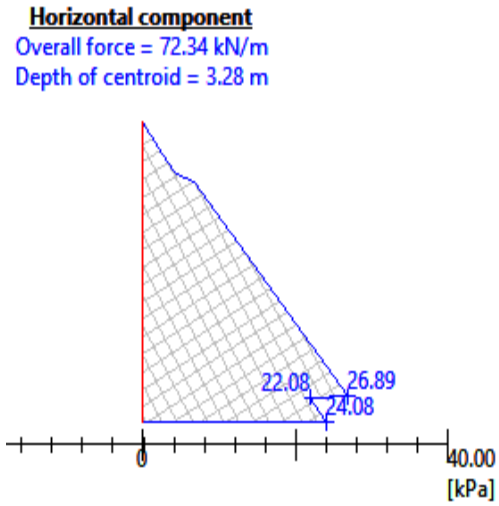
For SP with Terrain Profile – 8



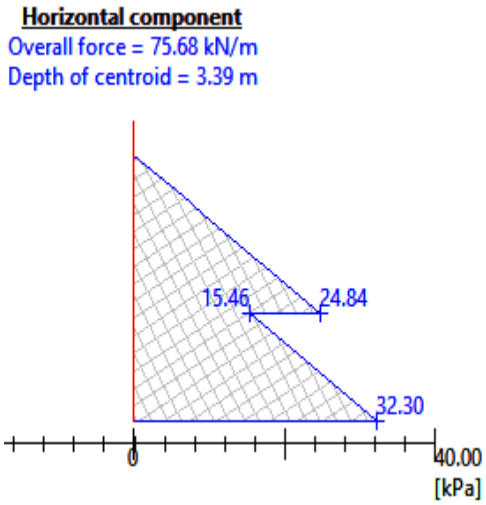
For CL with Terrain Profile – 8



For SP with Terrain Profile – 9



For CL with Terrain Profile – 9



For SP with Terrain Profile – 10

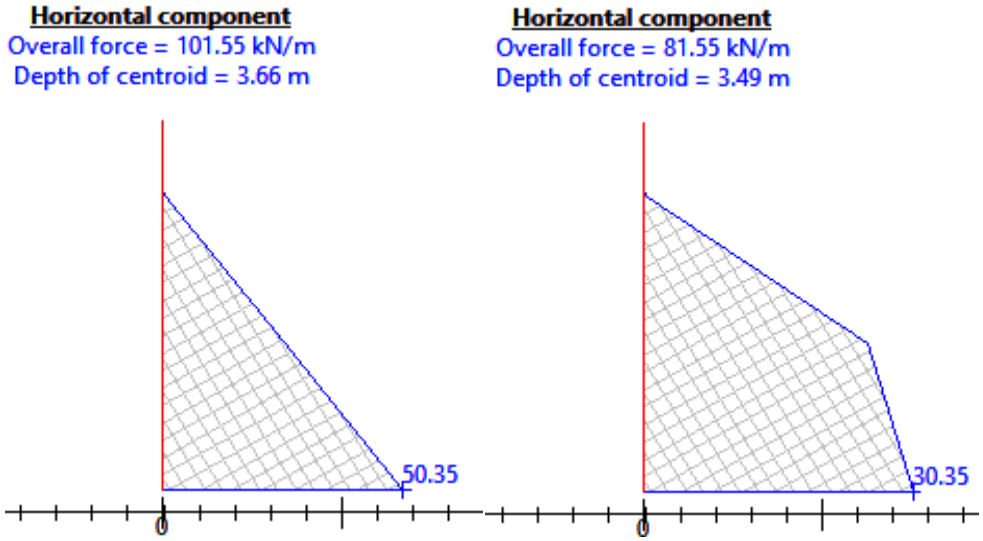
For CL with Terrain Profile - 10

Figure 3. Lateral earth pressures of SP and CL with respect to terrain changes

B. Earth pressure analysis with water table conditions

The earth pressure diagram for silty sand with Terrain Profile – 1 after taking the ground water table conditions is shown in Figure 4. It can be observed that the earth pressure is increased drastically with the water table and it is more with GWT condition-1 compared to GWT condition - 2. The earth pressure (horizontal force) for different soils under different terrain and water table conditions are given in Table 2. From these values it can be observed that the higher values of

earth pressure with water table conditions were obtained with SP as backfill for all the terrain profiles except Terrain profile – 7 where the earth pressure is maximum with CL. The increase in the overall force due to the effect of water table is in the range of 50 – 100%.



With GWT condition – 1 With GWT condition – 2

Figure 4. Earth pressure diagrams for SM with GWT conditions (Terrain – 1)

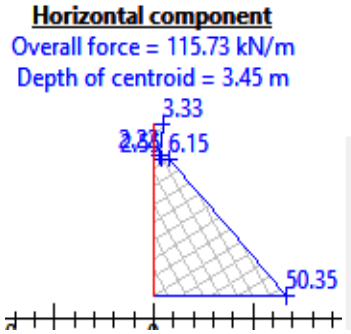
Soil	Overall force with SM (kN/m)		Overall force with SP (kN/m)		Overall force with CL (kN/m)	
Water Table Condition	GWT condition-1	GWT condition-2	GWT condition-1	GWT condition-2	GWT condition-1	GWT condition-2
Terrain profile – 1	101.55	81.55	119.37	99.37	101.11	81.11
Terrain profile – 2	106.7	86.7	124.93	104.93	112.24	92.24
Terrain profile – 3	106.7	86.7	124.93	104.93	112.24	92.24
Terrain profile – 4	98.79	78.79	115.39	95.39	97.28	77.28
Terrain profile – 5	124.31	104.31	138.02	118.02	136.71	116.71
Terrain profile – 6	121.33	101.33	137.15	117.15	119.87	99.87
Terrain profile – 7	141.88	121.88	149.14	129.14	179.58	159.58

Terrain profile – 8	91.68	71.68	110.52	90.52	82.78	62.78
Terrain profile – 9	85.48	65.48	104.31	84.31	82.56	62.56
Terrain profile – 10	119.24	99.24	136.01	116.01	119.87	99.87

Table 2. Earth pressures in soils with the effect of water table

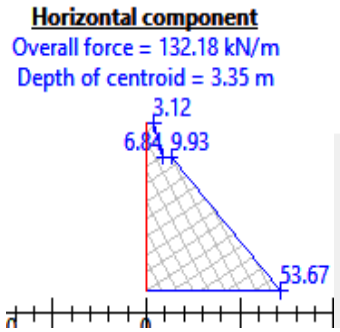
C. Earth pressure analysis with earthquake condition

To analyze the effect of earthquake forces on the value of earth pressure, the coefficients of horizontal and vertical accelerations (K_h and K_v) were assumed as 0.1. The effect of earthquake was analyzed with respect to each soil, terrain profile and water table condition. The results of SM, SP and CL with Terrain Profile – 1 and GWT condition – 1 is shown in Figures 5-7. The lateral forces due to weight of soil (active pressure), water table location (water pressure) and seismic effect (earthquake pressure) are also obtained separately and are presented in the Figures 5-7. The overall forces were compared for different cases and presented in Table 3. From these values, it can be observed that the effect of earthquake forces with the coefficients of accelerations assumed were lower than the values obtained with the water table condition (without earthquake effect). This shows the importance of pore water pressure calculation in the estimation of lateral earth pressure. The combined effect of water table and earthquake on various terrain profiles of the backfill showed that the highest lateral forces were obtained with SP (for Terrain Profiles – 1, 4, 8, 9 and 10) and CL (for Terrain Profiles – 2, 3, 5, 6 and 7). From this analysis, it can be understood that the terrain profile is having great importance in the estimation of earth pressure and it is influencing the values of lateral force along with the type of soil and water table conditions.



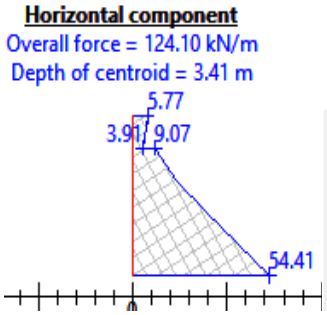
No.	Force	F_x [kN/m]	F_z [kN/m]	Applic. point x [m]	Applic. point z [m]
1	Active pressure	-21.55	4.58	0.00	3.61
2	Water pressure	-80.00	0.00	0.00	3.67
3	Earthq.- act.pressure	-14.19	3.02	0.00	1.97

Figure 5. Earth pressure diagram for SM with Terrain – 1 & GWT condition -1 (with earthquake pressure)



No.	Force	F_x [kN/m]	F_z [kN/m]	Applic. point x [m]	Applic. point z [m]
1	Active pressure	-39.37	8.37	0.00	3.16
2	Water pressure	-80.00	0.00	0.00	3.67
3	Earthq.- act.pressure	-12.81	2.72	0.00	1.96

Figure 6. Earth pressure diagram for SP with Terrain – 1 & GWT condition -1 (with earthquake pressure)



No.	Force	F_x [kN/m]	F_z [kN/m]	Applic. point x [m]	Applic. point z [m]
1	Active pressure	-21.11	4.49	0.00	4.02
2	Water pressure	-80.00	0.00	0.00	3.67
3	Earthq.- act.pressure	-22.99	4.89	0.00	1.94

Figure 7. Earth pressure diagram for CL with Terrain – 1 & GWT condition -1(with earthquake pressure)

Type of Backfill	Terrain Profile	Overall force (kN/m)	Overall force with GWT condition – 1 (kN/m)	Overall force with earthquake effect (kN/m)	Overall force with GWT condition – 1 and earthquake effect (kN/m)
SM	1	46.37	101.55	61.33	115.73
	2	55.57	106.7	77.41	130.57
	3	55.57	106.7	77.41	130.57
	4	40.86	98.79	52.5	109.37
	5	63.98	124.31	92.36	167.65
	6	60.1	121.33	82.74	146.76
	7	82.39	141.88	167.13	193.07
	8	30.06	91.68	39.4	99.98
	9	28.07	85.48	37.41	95.11

	10	60.1	119.24	76.72	135.4
SP	1	60.2	119.37	73.96	132.18
	2	68.7	124.93	87.29	143.49
	3	68.7	124.93	87.29	143.49
	4	54.11	115.39	65.19	125.41
	5	73.68	138.02	96.05	162.34
	6	73.24	137.15	91.43	156.4
	7	87.39	149.14	142.75	195.19
	8	46.48	110.52	55.6	118.61
	9	45.08	104.31	54.2	112.4
	10	72.34	136.01	87.35	150.2
CL	1	55.54	101.11	78.84	124.10
	2	75.9	112.24	132.39	169.43
	3	75.9	112.24	132.39	169.43
	4	46.87	97.28	62.83	112.00
	5	92.54	136.71	189.27	202.25
	6	75.68	119.87	143.56	179.41
	7	135.35	179.58	232.08	245.12
	8	29.94	82.78	43.12	95.99
	9	29.29	82.56	42.48	95.11
	10	75.68	119.87	103.67	149.48

Table 3: Comparison of earth pressures under different conditions of backfill

The overall forces due to various components are compared with respect to their terrain profiles and represented in Figures 8-10. In these figures, the symbol ‘AP’ represents the earth pressure due to weight of soil alone, ‘AP+WT’ represents the overall force due to the combined effect of active pressure and water pressure, ‘AP+EQ’ represents the condition with active pressure and earthquake pressure and ‘AP+WT+EQ’ represents the combined effect of active pressure, water table and earthquake. From these plots it can be observed that the terrain profile – 7 got the highest lateral force for all the three types of soils and for all the force conditions. The maximum values of lateral force for different soils with the force condition ‘AP+WT+EQ’ are in the range of 190 – 250 kN/m.

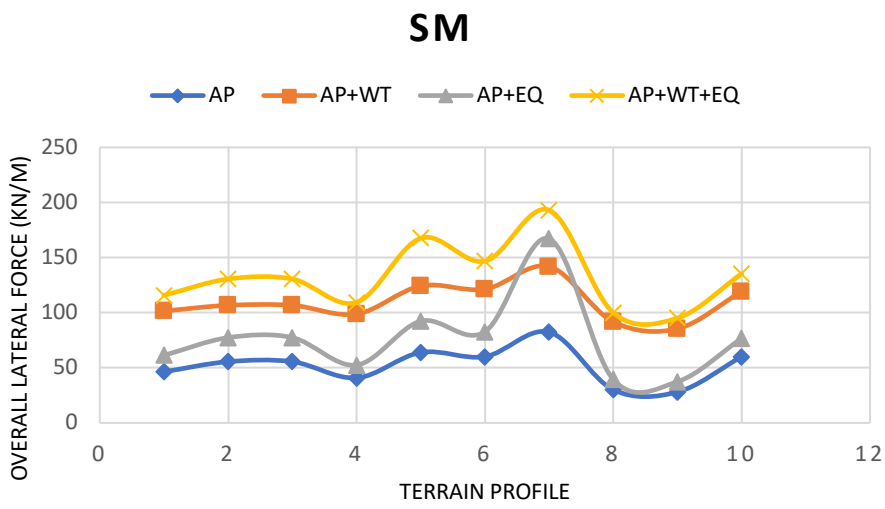


Figure 8. Lateral forces with SM with respect to various conditions and terrain profiles

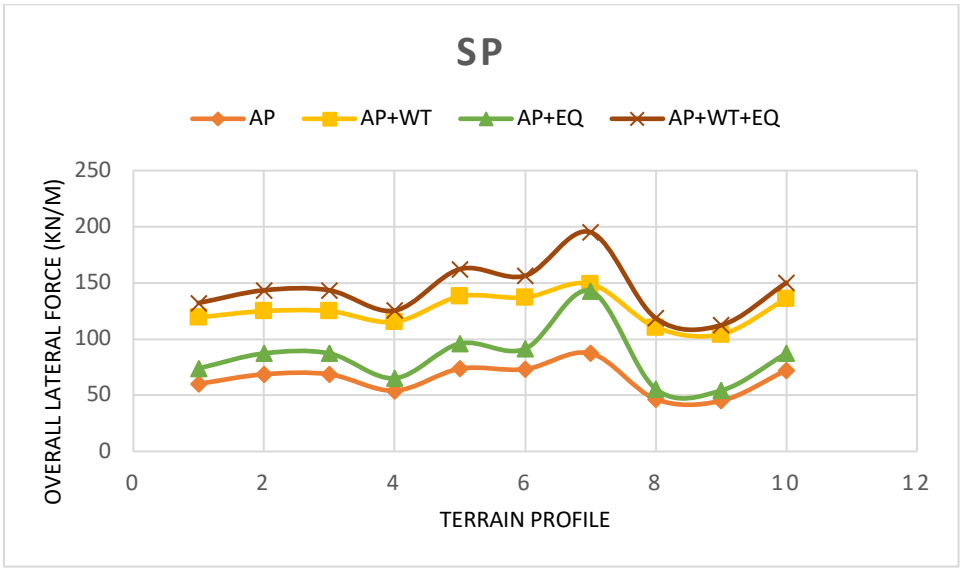


Figure 9. Lateral forces with SP with respect to various conditions and terrain profiles

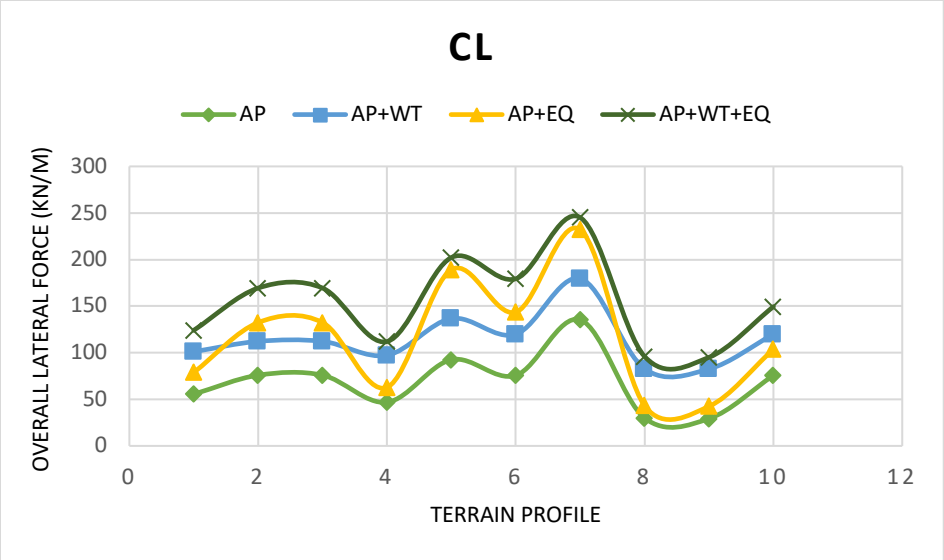


Figure 10. Lateral forces with CL with respect to various conditions and terrain profiles

CONCLUSION

The lateral earth pressure analysis was carried out with three types of soils as backfill and ten types of terrain profiles to know the effect of soil type and terrain type on the value of lateral earth pressure. The effects of water table and earthquake forces were also analyzed with respect to each soil. The earth pressure has drastically increased with the raise in ground water table. The earth pressures with different soils were highest corresponding to the terrain profile – 7 whereas it was least with the terrain profile – 9 with all the conditions studied. The lateral force due to the combined effect of active pressure and water table are consistently higher than the values obtained with the combined effect of active pressure and earthquake forces for all the soils and terrain profiles except for the terrain profile – 7. Therefore, it was identified that the terrain profile has great influence on the lateral earth pressure. The terrain profile with a backfill at a level higher than the level of retaining wall has shown higher values of earth pressure when compared with the terrain profile where the backfill is at lower level than the retaining wall. Hence, it was concluded that the terrain profile has to be verified and should be levelled before constructing the retaining wall to avoid additional earth pressure on the retaining wall and to get an economical design.

Conflicts of Interest:

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Funding Statement:

No funding is received for this research work.

Data Availability:

The data used to support the findings of this study are included within the article.

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