Journal of Harbin Engineering University
ISSN: 1006-7043
Vol 44 No. 9
September 2023

Variation of Earth Pressure on Retaining Wall for Different Wall Movement

Dr. Tejas Bhatkar[1], Dr. Shrikant Tekade[2], Dr. Anirban Mandal[3]
[1] Geotech Engineer, SD Geotesting Solutions & Consultant, Amravati (M.H.) India
[2] Assistant Professor, Government College of Engineering, Nagpur (M.H.) India
[3] Associate Professor, Visveswaraya national Institute of Technology, Nagpur (M.H.)India

Abstract- Retaining wall is the rigid wall usually constructed to withstand the lateral pressure of soil on their backfill. Thus, retaining wall plays a very important role in many structures considering economic and safety design of retaining wall depends on proper estimation of earth pressure. In this research paper, FEM based numerical model was developed to estimate the earth pressure for different wall movement conditions. The numerical model results were compared with the experimental model results. The earth pressure on retaining wall for four conditions was analyzed i.e. at rest, h/4, active and passive conditions with varying surcharge loading. The model results show the same trend as of experimental study. Overall from model study in general we can conclude that lateral stress is higher for higher depth as compared with shallow depth.
Keywords: Retaining wall, Cohesionless soil, Earth pressure, Surcharge Pressure, Numerical modelling.

1 Introduction

Earth retaining structures are designed to withstand the forces exerted by the backfill and other external forces. Retaining wall usually carries earth, water and surcharge pressure on their backfill and these gets transfer to foundation safely. The various application of retaining wall are bridge abutments, culvert walls, flood walls, waterfront structures and new or widened highway in developed areas, mountains or steep slopes. Economic and safe design of retaining wall depends on proper estimation of earth pressure.

Nowadays it became vital need to address at most of the deep excavation being carried out in densely populated urban area. Therefore, out most care must be taken to ensure the stability of existing structure before any such excavation.

Lateral earth pressure is a type of force exerted by the soil to adjoining retaining structures. Therefore, lateral earth pressure need to be taken into consideration which was developed by various types of surcharge loading. Basically there are three type of stress in soil active, at rest and passive. Various researchers carried out experiments on rigid retaining wall. [3] justified that the stress near the top of the retaining wall increases beyond the level of the at-rest stress and due to arching effect the stress distribution is nonlinear. Based on the general wedge theory, the passive pressure distribution is linear and in good agreement with Terzaghi's prediction.

Various experiments were carried out on wall with rotation above its base (RB) or rotation above its top (RT) mode. [4] described the modes of wall movements has a significant effect on the generation of earth pressure. [5] justified that irrespective of the backfill density, passive thrust attained a constant value after a wall movement of about 14 % of wall height. The new earth pressure equations established by [16] were based on Coulomb and Rankine's theories used. The equation can be used for any lateral deformation for cohesion less soil (normally consolidated) for at rest, active and passive state of stress.

[14] studied damped character of pressure due to surcharge loading through large scale model and concluded that it occurs maximum at the surface and a minimum at the base of the wall. [12] highlighted that the surcharge effect was constant for all possible slip planes and the maximum pressure on a retaining wall with and without a surcharge will correspond to the same surface of sliding, based on [14] experiments.[9],[13] studied boussinesq elastic based solution. [9] provided solutions for lateral stresses on the wall due to the strip load. This general solution is applicable for both yielding and unyielding retaining wall structures whereas, [13] extended Coulomb approach more reasonable for active state and recommended that elastic solution is more applicable for unyielding structures. [9],[15] described lateral force and centroid location was quite different for both isotropic and anisotropic

backfills. [6] through experimental work studied that lateral pressures on sheet pile walls were lower than those obtained using the elastic approach but closer as predicted by Coulomb's method.

For inclined retaining wall, [7] proposed formulation for determination of active earth pressure, angle of failure wedge and application point of resultant force. Whereas, for circular retaining wall [10] proposed stress characteristics method in presence of soil wall adhesion which is used for investing active lateral earth pressure on a circular retaining wall for that investigator implement superposition principle for determining lateral earth pressure coefficient whereas, for inclined retaining wall necessary parameter are extracted by Pseudo-static seismic coefficient and horizontal slices method.

[8] gives comparison between integral bridge abutment and abutment of conventional bridges for the traffic surcharge condition. For dynamic earth pressure using FLAC program a numerical modelling has been developed also to represent the soil behaviour Mohr-Coulomb criteria has been used. Using model study investigators found that the significant changes occurred in both quantity and distribution of earth pressure behind the abutment when using integral bridges.

[11] evaluated lateral earth pressure due to surcharge load and studied that the pressure was greater near the surface but reduces nonlinearly throughout the height of the wall. [1] experimentally justified that the earth pressure on retaining wall under surcharge loading when wall moves from backfill, there is continuous decrease in earth pressure when wall moves towards backfill

To determine the magnitude of the lateral pressure to which the structure is subjected soil-retaining structures such as retaining walls is designed. The lateral pressure behind a wall depends on whether the wall is going away from soil or towards soil.

The main objective of this study is to investigate magnitude and variation of lateral earth pressure acting on retaining wall due to surcharge loading, when wall moves either away from backfill i.e. active condition or towards backfill i.e. passive condition from its original at rest position for various cases such as

1. Retaining wall at at-rest condition with varying surcharge loading.
    a. Edge of the surcharge load is adjacent to the wall.
    b. Edge of the surcharge loading is at a distance of h/4 from the wall, where h is the height of backfill.
2. When Retaining wall moves away from backfill, under surcharge loading of 50 kPa.
3. When Retaining wall moves towards the backfill, under maintained surcharge loading of 50 kPa.

The validation of this is done with experimental data results obtained from [1] using finite element software with variation and distribution of earth pressure on retaining walls, subjected to various surcharge loading.

2 Experimental Description

[1] carried out experimental work to find out the magnitude, variation and distribution of earth pressure on retaining walls for at rest, h/4, active and passive conditions. Their experimental work is conducted in a tank of stainless steel having dimension 1.2 m X 0.31 m X 0.7 m. The model retaining wall of dimension 0.7 m height, 0.305 m width and 16 mm thickness was made of stainless steel plate. By using specially designed clamps the wall was placed in the test tank 0.3 m away from the non-backfill end and hinged to the bottom. The three sides of the test tank was perfectly welded consisting of 16 mm steel plates while a longer side of thick Perspex sheet consist of 25 m. The tank bottom consisted of 5 mm plywood which was placed above the bottom steel plate. Epoxy resin was spread and sprinkled on the bottom steel plate with the same sand as that used as backfill. The tank were placed with 10 cm wide greased polyethylene sheets of 60 µm thick with an overlap of 1 m from all the sides in order to achieve plane strain conditions.

The sand bed developed by [2] was prepared using a travelling pluviator consisting of an orifice and diffuser system. The orifices of different sizes were used so that sand flow from the hopper can be regulated. The sand used in the experiments was Indian Standard sand of Grade-II, classified as SP as per unified soil classification system. In order to achieve 68 % relative density the backfill sand was compacted. The friction angle is 30^0 obtained from direct shear test. A mechanical jack of 20 ton capacity was fixed to the non-backfilled side of test tank and connected to a steep strip. This jack assembly was used to hold the retaining wall in a position so that at rest condition can be achieved and also to achieve active and passive condition by applying lateral movement to the wall. The wide space on the backfill side of 0.3 m was used to place the jack assembly. There was total 7 diaphragm type earth pressure cells (EPC) placed with retaining wall surface. To observe relative wall movement, markers were placed in the backfill vertically at 0.2, 0.3, 0.4, 0.5, 0.55 and 0.6 m height from the tank bottom. The uniformly distributed surcharge load was applied on the backfill in the range of 0-50 kPa after backfilling the sand up to 60 cm height in the test tank. Throughout the experiments the earth pressures sensed by EPCs were constantly monitored.

Thus, the magnitude and variation of at-rest earth pressures were measured along the height of the wall for at rest and h/4 condition. At rest condition (1st case) is when a surcharge (0-50 kPa) was placed adjacent to the face of the wall and h/4 is at h/4 (2nd case) i.e. 0.15 m distance away from the wall. In same way, magnitude and distribution of earth pressure were measured when wall moves away and towards the backfill i.e. active (3rd case) and passive condition (4th case) by maintaining constant surcharge load of 50 kPa.

3 Numerical Modelling

Finite element software PLAXIS 2D was used to model the retaining wall of stainless steel plate 5m height in a 5 m x 5m model test tank. Upto 3m of the tank height was filled with sand as in experimental setup of [1] model and other properties are given in Table 1. The type of analysis was plastic with zero water density. The surcharge pressure uniformly distributed and increased in steps from 0- 50 kPa applied on backfill area of 3 m. This loading only varies in case of h/4 condition where edge of the surcharge loading is at a distance of h/4 from the wall.

Table 1 Physical Properties of sand.

Parameters Mohr- Coulomb Model	**Value**
ϒ	16.96 (kN/m^2)
μ	0.33
C	0
Φ	30

Mohr coulomb material model was used for sandy soil with fine meshing. The retaining wall is modelled by mean of a plate whose properties are as shown in Table 2 placed and 3 m away from the non backfilled end. The bottom boundary is fixed (horizontally and vertically) and the lateral boundaries to be free only in vertical direction. The plane strain condition is taken as per in experimental setup where the strain in the direction of z-axis is zero.

Table 2 Properties of Retaining wall and Anchor rod.

Parameters	**Value**
EA	2.465X10^6 (kN/m)
EI	2.958X10^7 (kNm^2/m)
μ	0.2
EA for Anchor rod	2x10^5 kN

The non backfill side of 2.0 m wide was used to place fixed end anchor represented by a rotated T with a fixed end horizontally to rotate wall as in case of experimental setup [1]. Relative wall movement was obtained at various depths 0.54, 0.4, 0.39, 0.29, 0.21, 0.11 and 0.04 m. Surcharge pressure in the range of 0-50 kPa was applied on the backfill. This pressure was increased in steps of 10 kPa . Thus, magnitude and variation of earth pressure at rest condition, surcharge load at a distance of h/4 from the wall, active condition and passive condition obtained along the height of the wall for various depths discussed below. The dimension of the geometry model and retaining wall is same for all cases only difference is of surcharge loading, prestress force, number of fixed end anchor, number of excavation layer. The properties of retaining wall, fixed end anchor and sand is same for all conditions while only stiffness of sand varies according to condition of the case. The Plastic type of analysis is carried out for all cases.

The analysis is carried out in PLAXIS 2D for at rest condition with incremental surcharge pressure, when the edge of the surcharge load is adjacent to the wall. The load is increased from 0-50 kPa. The nonback fill and backfill area consists of sandy soil of stiffness $25x10^3$ kN/m^2. The 2.0 m nonback fill area was excavated to full height 5 m in steps. The fixed end anchor is attached on non-back fill area. The retaining wall and anchor rod properties are as given in Table 2. The prestress force for fixed end anchor rod is constant i.e. zero for all surcharge loading from 0-50 kPa. The complete geometry of model is as shown in Figure 1.

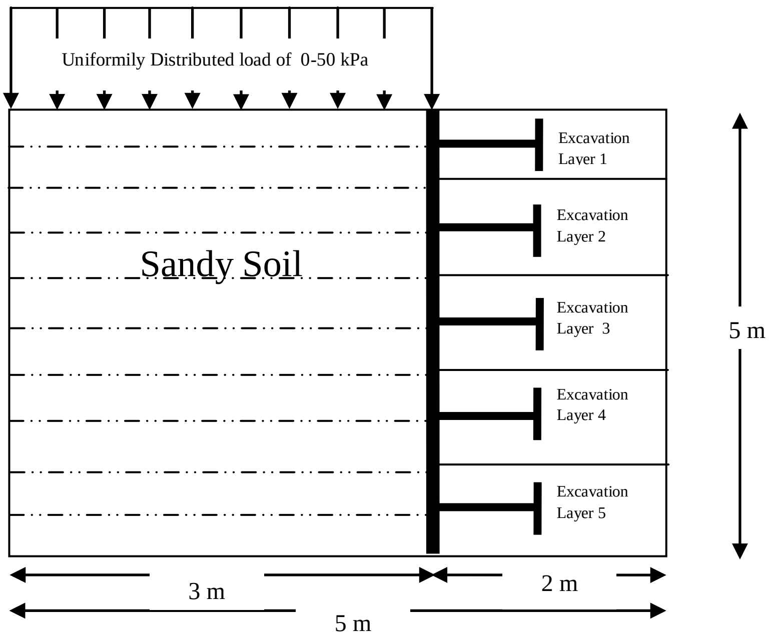

Figure 1. Complete geometry of model for at rest condition.

When the edge of surcharge loading is at a distance of h/4 from the non backfill soil wall, where h is height of backfill i.e. 5.0 m. The nonback fill and backfill area consists of sandy soil with a stiffness 4200 kN/m^2. The prestress force for fixed end anchor rod is constant i.e. zero for all surcharge loading from 0-50 kPa. Steel plate properties same as retaining wall provided on top surface of model tank. The loaded area is more as compared to unloaded area so as to avoid failure due to heavy uniform loading of 30-50 kPa steel plate is provided. The excavation is carried out as shown in Figure 2.

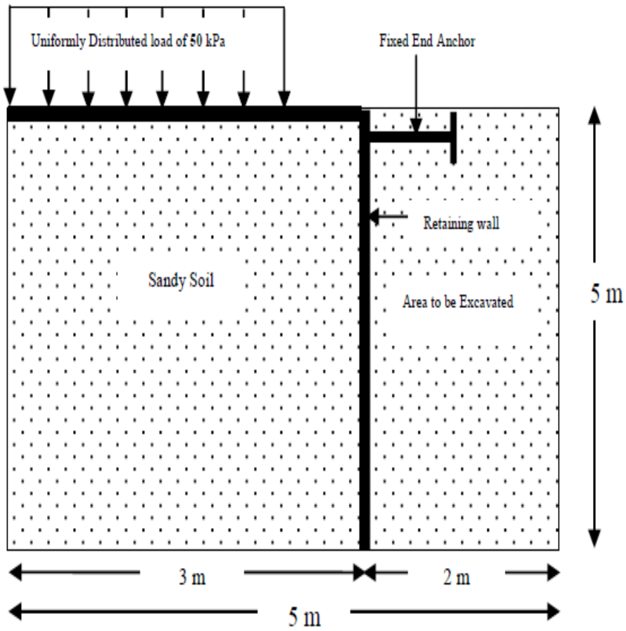

Figure 2. Complete geometry for h/4 condition.

Active and passive condition is the one in which the retaining wall moves away from backfill and towards the backfill. Thus, the complete geometry for active condition i.e the retaining wall moves away from the backfill is as shown in Figure 3, under maintained surcharge loading of 50 kPa as carried out in experimental setup. The properties of sand and wall are similar as used in at rest and h/4 condition. The 3.0 m wide backfill side soil having stiffness 4200 kN/m^2 while 2.0 m thick non back fill soil contain different stiffness to match the angle for active condition as in case of experimental study. The wall movement is carried out by changing prestress force of fixed end anchor with stepwise excavation. The various angles θ_1 to θ_7 for which lateral stress is calculated are as 0^0 1' 38.59'', 0^0 2' 40.06'', 0^0 5' 11.05'', 0^0 6' 19.11'', 0^0 7' 11.92'', 0^0 11' 30.57'', 0^0 14' 32.49''.

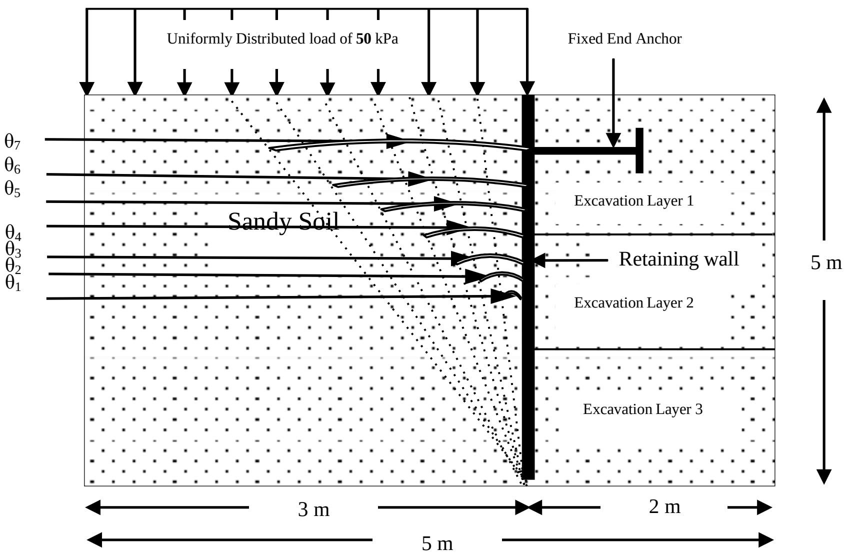

Figure 3. Complete geometry for active condition.

In 4th case retaining wall moves towards the backfill i.e. Passive condition, under maintained surcharge loading of 50 kPa. The stiffness of soil is 4200 kN/m^2 for complete geometry. The wall movement is carried out by fixed end anchor with variation in prestress force to match the angle as in experimental case. The prestress force of 98.07 kN was considered as applied in experimental setup by mechanical jack. The excavation is carried out as shown in Figure 4. The excavation here is carried out in one layer to its full height i.e. 5 m. The various angles θ_1 to θ_5 for which lateral stress is calculated are as 0^0 1' 21.27'', 0^0 5' 55.19'', 0^0 8' 52.57'', 0^0 11' 49.96'', 0^0 17' 58.34''.

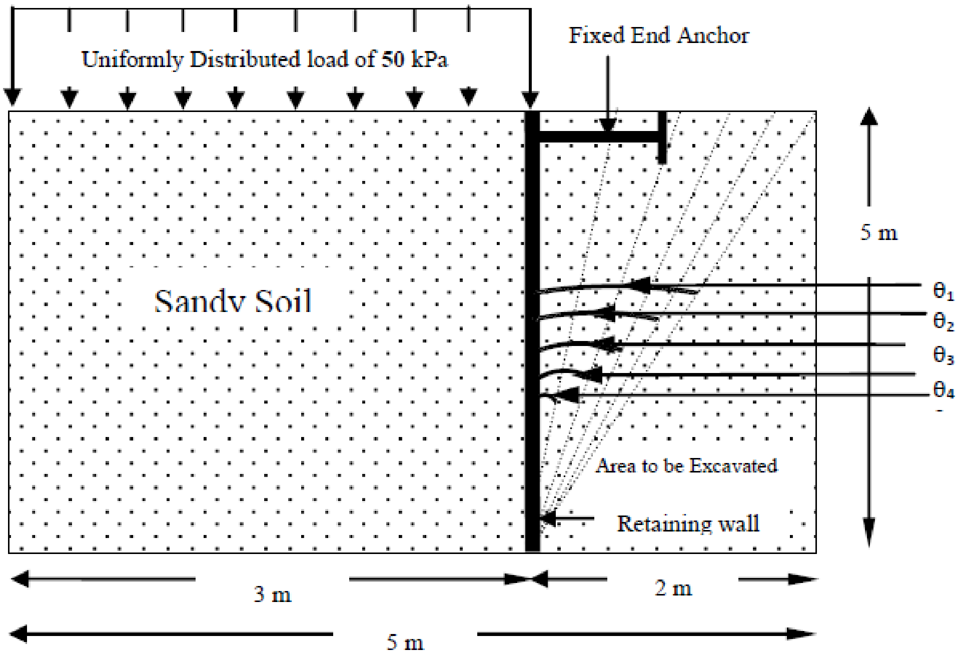

Figure 4. Complete geometry for passive condition .

4 Results and Discussions

The results from model study were plotted for lateral stress variation with depth along the wall for at rest condition, load at h/4 distance from the wall, active and passive condition. The results were then compared with [1] experimental results. The lateral stress for various depths along the height of the wall for all condition one by one is given as follows. The lateral stress variation along the height of the wall with loading from 0-50 kPa is shown in Table (3, 4) for at rest and h/4 condition. The lateral stress for various depths along the height of the wall for various angles is as given in Table (5, 6) for active and passive condition for constant 50 kPa surcharge loading.

Table 3 Lateral stress variation with depth for surcharge loading 0-50 kPa for at rest condition.

Depth (m)	Lateral Stress (kN/m^2)					
	No Surcharge	10 kPa	20 kPa	30 kPa	40 kPa	50 kPa
0.54	3.56	5.45	9.09	10.75	15.01	18.12
0.47	2.62	5.58	8.12	9.58	12.02	17.06
0.38	1.93	5.04	9.63	12.34	14.84	16.88
0.29	1.53	5.20	7.27	10.28	13.22	15.97
0.21	1.11	3.98	6.26	10.02	13.88	15.03
0.12	0.66	4.22	6.98	9.36	11.09	14.75

Table 3 illustrate that lateral stress increases as surcharge load increases from 0-50 kPa. For higher depth of 0.54 m, the stress is higher than lower depth of 0.12 m in all cases from 0-50 kPa. Along with depth lateral stress get reduces from higher to lower for all surcharge loading cases (i.e. 0-50 kPa).

Table 4 Lateral stress variation with depth for surcharge loading 0-50 kPa for h/4 condition.

Depth (m)	Lateral Stress (kN/m^2)					
	No surcharge	**10 kPa**	**20 kPa**	**30 kPa**	**40 kPa**	**50 kPa**
0.54	2.8	5.01	5.34	7.29	8.30	11.80
0.47	2.25	2.75	2.82	3.69	6.01	8.30
0.38	1.91	1.62	1.64	1.46	2.82	5.32
0.29	1.61	1.54	1.47	1.73	1.38	1.48
0.21	0.99	0.94	0.94	0.93	1.03	1.01
0.12	0.55	0.55	0.52	0.55	0.59	0.59

Table 4 illustrate that lateral stress increases from 0-50 kPa also the magnitude of lateral stress is higher for higher depth and low for lower depth for each loading condition.

The lateral stress variation with depth along the wall for various wall movements i.e. angle θ_1 to θ_7 is given in Table (5, 6) for active and passive condition. Corresponding Figure 7 and Figure 8 illustrate comparative graph of experimental and model study for lateral stress with depth for various angles in active and passive condition

.

Table 5 Lateral stress variation with depth for surcharge loading 50 kPa for active Condition.

Depth (m)	Lateral Stress (kN/m^2)						
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7
	$0^0$1'38.59''	**$0^0$2'40.06''**	**$0^0$5'11.05''**	**$0^0$6'19.11''**	**$0^0$7'11.92''**	**$0^0$11'30.57''**	**$0^0$14'32.49''**
0.54	18.51	19.5	15.41	14.48	19	21.53	20.12
0.47	16.73	24.76	15.35	16.83	18.64	21.42	19.58
0.38	14.99	25.37	17.14	16.91	18.33	19.12	15.98
0.29	15.42	25.44	19.08	19.43	18.14	18.55	19.26
0.21	15.88	27.51	17.52	16	15.66	15.4	15.5
0.12	15.84	30.07	15.79	15.6	14.34	14.94	15.02

Table 5 gives variation of lateral stress with depth for 50 kPa. For angle θ_1, lateral stress is minimum at lower depth in comparison to higher depth but for θ_2, θ_3, θ_4 reverse condition occurs. For θ_5, θ_6, θ_7 lateral stress is higher for higher depth and lower for lower depth. Considering single depth with varying angles lateral stress increases for alternate angle condition.

Table 6 Lateral stress variation with depth for surcharge loading 50 kPa for passive Condition.

Depth (m)	Lateral Stress (kN/m²)				
	θ1	θ2	θ3	θ4	θ5
	0⁰ 1' 21.27''	**0⁰ 5' 55.19''**	**0⁰ 8' 52.57''**	**0⁰ 11' 49.96''**	**0⁰ 17' 58.34''**
0.54	31.09	43.11	48.00	52.89	63.02
0.47	30.88	43.06	48.00	52.95	63.21
0.38	30.69	43.10	48.14	53.18	63.64
0.29	29.89	42.64	47.82	53.00	63.75
0.12	30.56	55.78	66.02	76.27	97.47

Table 6 illustrates that as angle goes on increasing with depth the lateral stress goes on increasing. The stress is high at higher depth and become low at lower depth. However, for depth 0.54 m to 0.29 m the stress is almost constant and the lateral stress increases suddenly for lower depth.

4.1 Comparison

The lateral stress results were plotted for all the conditions i.e. at rest, h/4, active and passive condition and the comparative plot between experimental and model study is shown step by step. The lateral stress is high in model study as compared to [1] experimental results for the same case.

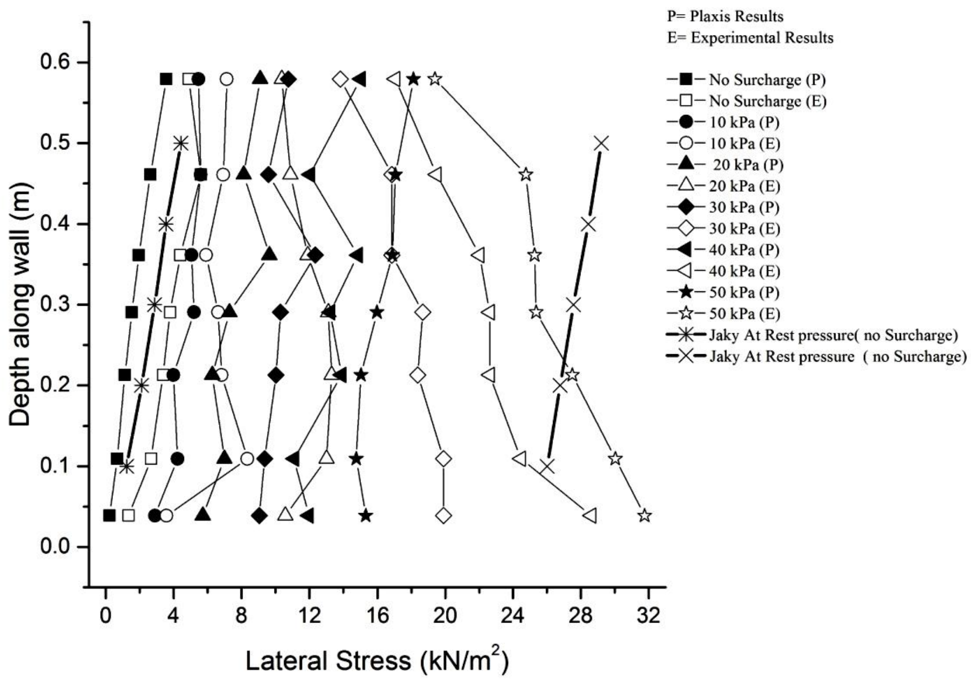

Figure 5. Comparison plot of lateral pressure with depth for experimental and model study for at rest condition.

The lateral stress for experimental and model study increases from higher to lower depth with respect to loading as shown in Figure 5. The lateral stress is observed higher at higher depth while minimum for lower depth. Thus, experimental and model study results are following the same trend.

The percentage lateral stress difference for experimental and model study with respect to depth is given below. For the depth 0.54 m, lateral stress difference from no surcharge case to 50 kPa is between 6.53 to 27.12 %. For depth 0.47 m, lateral stress difference is between 19.25 to 53.16 %. For depth 0.38 m, lateral stress difference from is between 14.61 to 55.82 %. For depth 0.29 m, lateral stress difference is between 21.36 to 59.36 %. For depth 0.21 m, percentage lateral stress difference is between 38.66 to 66.84 %. For depth 0.12m, percentage lateral stress difference is between 46.25 to 75.13 %. For depth 0.04 m, percentage lateral stress difference is between 18.93 to 84.14 %. Thus, for the case of at rest condition, experimental stress results are higher than the model stress results for each loading case i.e. (0-50 kPa). The percentage lateral stress difference for all depth is maximum for no surcharge case.

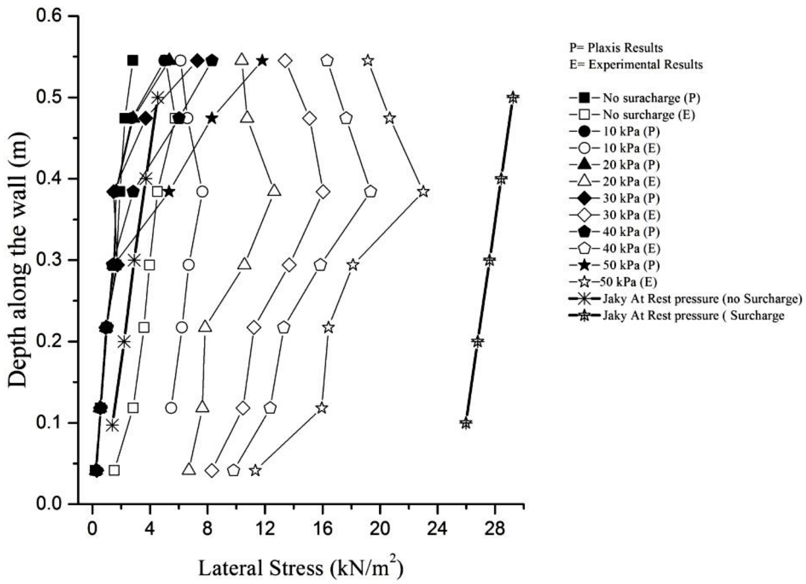

Figure 6. Comparison plot of lateral pressure with depth for experimental and model study for h/4 condition.

For h/4 condition, the plot shows that with the increase in depth for loading 0-50 kPa the lateral stress goes on decreasing as the distance between surcharge load and retaining wall increases. The model responds in good agreement with the experimental results as shown in Figure 6.

The percentage lateral stress difference for various depths is as follows. For depth 0.54 m, the percentage lateral stress difference from no surcharge case to 50 kPa is between 18.27 to 49.08 %. For depth 0.47 m, lateral stress difference is between 59.81 to 75.49 %. For depth 0.38 m, lateral stress difference is between 57.74 to 90.83 %. For depth 0.29 m, lateral stress difference is between 58.08 to 91.78 %. For depth 0.21 m, lateral stress difference is between 72.34 to 93.8 %. For depth 0.12 m, lateral stress difference is between 80.56 to 96.24 %.

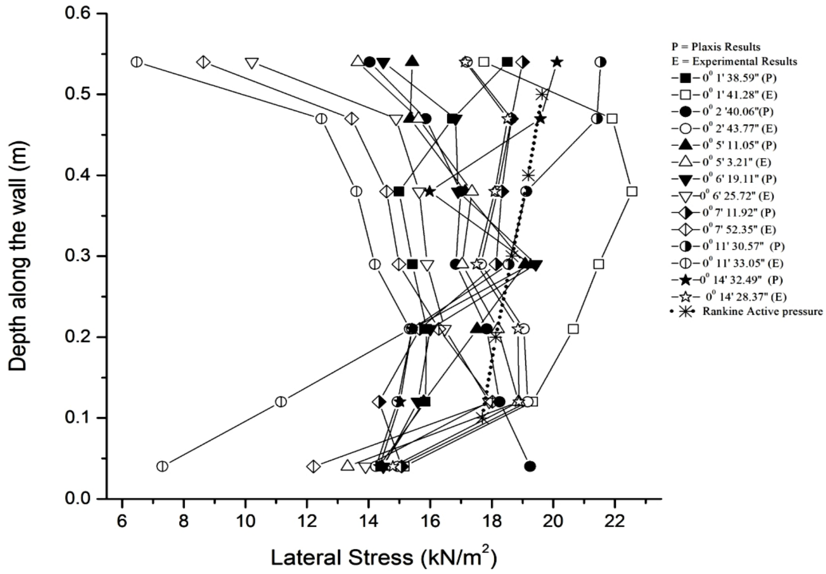

Figure 7. Comparison plot of lateral pressure with depth for experimental and model study for active condition case.

The graph shown in Figure 7 is plotted between lateral stress and depth along the wall for different angles (i.e. wall movement away from the backfill, active condition) with experimental and model study results. From the plot it is observed that for both the cases first the lateral stress value increases with depth and angle then get constant and again increases. The percentage lateral stress difference for angles θ_1 to θ_7 with respect to depth is as follows. For depth 0.54 m, the percentage lateral stress difference from θ_1 to θ_7 is between -232.76 to 28 %. For depth 0.47 m, the lateral stress difference is between -71.77 to 35.98 %. For depth 0.38 m, the lateral stress difference is between -40.58 to 33.53 %. For depth 0.29 m, the lateral stress difference is between -41.22 to 33.8 %. For depth 0.21 m, the lateral stress difference is between -14.31 to 35.15 %.For depth 0.12 m, the lateral stress difference are between -43.8 to 39.29 %.

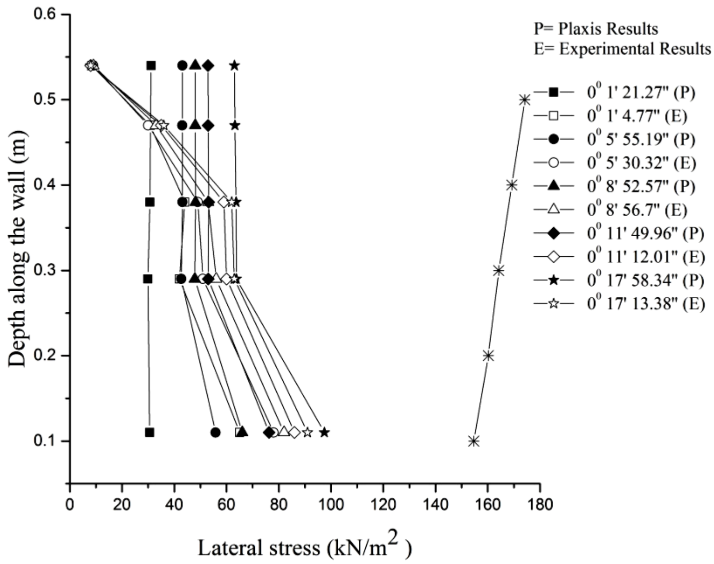

Figure 8. Comparison plot of lateral pressure with depth for experimental and model study for passive condition case.

The plot shows in Figure 8 that with the increase in angle the lateral stress value increases for various depths. The percentage lateral stress difference for angles θ_1 to θ_5 with respect to depth is as follows. For depth 0.54 m, the lateral stress difference from θ_1 to θ_5 is between -687.75 to -268.8 %.For depth 0.47 m, the lateral stress difference is between -75.58 to -0.61%.For depth 0.38 m, the lateral stress difference is between -2.64 to 30.25 %.For depth 0.29 m, the lateral stress difference is between -1.19 to 28.83 %.For depth 0.12 m, the lateral stress difference is between -7.1 to 52.98 %.

5 Conclusion

In this study FEM based numerical model was developed to estimate the earth pressure for different condition of wall movement. Present model estimate earth pressure reasonably accurate when compare with experimental results such model can be used by professional for prediction of earth pressure in active and passive condition to ensure the stability of structure with optimize design. Few specific conclusions can be drawn from different parametric study to understand the mechanism as given below

1. For at rest condition by comparing model results with experimental results, model results gives good prediction about the lateral stress.
2. The model and experiments lateral stress results shows same trend for h/4 condition.
3. In case of active and passive condition, the percentage error by model study is less as compared with experimental study for varying angle condition.
4. In case of at rest and h/4 condition, the lateral stress increases for higher depth i.e. 0.54 m as the surcharge load increases from 0-50 kPa.
5. In case of active condition, the lateral stress is minimum near the base and lateral stress value changes with varying angles.
6. In case of passive condition, the lateral stress increases as the depth and angle increases.
7. Overall from model analysis it can be concluded that the lateral stress is higher for higher depth as compared with shallow depth.

References

[1] Dave NT, Dasaka MS.: Transition of earth pressure on rigid retaining walls subjected to surcharge loading, *International Journal of Geotechnical Engineering,* 6, pp 427-435, 2012.

[2] Dave NT, Dasaka MS.: Assessment of portable travelling pluviator to prepare reconstituted sand specimens, *Geomechanics and Engineering,Techno-Press*, 4(2), pp 79-90, 2012.

[3] Fang Y, Ishibashi I.: Static earth pressures with various wall movements, Journal of Geotechnical Engineering, 112 (3), pp 317-333, 1986.

[4] Fang YS, Chen TJ, Wu BF.: Passive earth pressures with various wall movements, *Journal of Geotechnical Engineering* ,ASCE 120(8), pp 1307-1323, 1996.

[5] Fang YS, Lee CC, Chen TJ.: Passive earth pressures with various backfill densities, *Proc. of 6th ICPMG- Phy. Mod. in Geotech*, Taylor and Francis Group, London pp 1081-1086, 2006.

[6] Georgiadisl M , Anagnostopoulos C.: Lateral pressure on sheet pile walls due to strip load, *Journal of Geotechnical and Geoenvironmental Engineering,* 124(1), pp 95-98, 1998.

[7] Ghanbari A , Ahmadabadi M.: Active earth pressure on inclined retaining walls in static and pseudo- static conditions*, International Journal of Civil Engineering,* 8(2), pp 159-173, 2010.

[8] Hosseini S, Khatibi F.: Earth pressure behind an integral bridge abutment under traffic loadings, *Arabian Journal for Science and Engineering,* 38(10), pp 2619-2629, 2013.

[9] Jarquio R.: Total lateral surcharge pressure due to strip load, *Journal of Geotechnical Engineering* ASCE 107(10), pp 1424-1428, 1981.

[10] Keshavarz A, Ebrahimi M.: The effects of the soil-wall adhesion and friction angle on the active lateral earth pressure of circular retaining walls, *International Journal of Civil Engineering* 14(2), pp 97-105, 2016.

[11] Kim SJ , Barker MR.: Effect of live load surcharge on retaining walls and abutments, *Journal of Geotechnical and Geoenvironmental Engineering,* 128(10), pp 803–813, 2002

[12] Shvetsov GI.: Earth pressures on retaining walls under the effect of a uniform load, *Gidrotekhnicheskoe Stroitel'stvo* 5, pp 25-27, 1974.

[13] Steenfelt J S, Hansen B.: Discussion of total lateral surcharge pressure due to strip load, *Journal of Geotechnical Engineering* ASCE, 109(2), pp 271-273, 1983.

[14] Vargin M N.: Effect of continuous surcharge on a retaining wall, *Fundamentry i Mechanika Gruntov,* 3, pp 8-10, 1968.

[15] Wang C.: Lateral force induced by rectangular surcharge loads on a cross-anisotropic backfill, *Journal of Geotechnical and Geoenvironmental Engineering,* 133(10), pp 1259–1276, 2007.

[16] Zang JM, Shamoto Y, Tokimatsu K.: Evaluation of earth pressure under any lateral deformation, *Soils and Foundations*, 38(1), pp 15-33, 1998.