IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 3 Ser. IV (May. - June. 2019), PP 08-20
www.iosrjournals.org

Effect of Gradation on Active Earth Pressure of Cohesionless Soil behind Retaining Wall

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Abstract: *Design and construction of soil retaining structure consist of an important part of road and railway projects. Hence, accurate estimation of Active earth pressure is necessary for the safe and economical design of retaining structure. Active earth pressure is one of the important factor for design of retaining wall. The magnitude of active earth pressure depends upon the type of backfill material used. In this research, natural sand, artificial sand and C-ϕ soil have been used and sieve analysis, specific gravity and direct shear tests have been carried out. Accordingly the sands and soil have been determined as poorly graded and well graded. By using the value of internal friction obtained from direct shear test, the active earth pressure will be calculated by four different theories viz (Rankine's, Coulomb's, Culman's and Rehbann's) for four different soils. In case of retaining wall designed using crusher sand as a backfill material, it was found that active earth pressure decreases. Active earth pressure is maximum for c-ϕ soil and minimum when crusher sand is used as a backfill, whereas natural sand shows intermediate values of active earth pressure in between crusher sand and c-ϕ soil.*

Keywords: *Gradation, direct shear test, internal friction angle, active earth pressure, backfill, retaining wall.*

Date of Submission: 25-05-2019 Date of acceptance: 10-06-2019

I. Introduction

Active earth pressure is one of the most important factor in the design of retaining wall. Active earth pressure refers to a state of stress in a backfill which is developed when retaining wall is pushed away from it. The main concern in retaining wall failure analysis is the determination of magnitude of lateral earth pressure on the retaining wall. In retaining wall active earth pressure contributes to the failure of the wall. Generally, a cohesionless granular soil should be used as a backfill to allow the water to penetrate the soil, to reach the drains or weep holes. If cohesive soil is used such as clay it will be difficult for the water to reach a depth where it can enter the pipe or weep hole. Granular materials allow water to permeate, rather than keeping it trapped within. As gravity pulls the water downward, the granular backfill lets the water freely pass until it reaches weep holes or pipes. The grading behind retaining wall also has an effect on the buildup of water. The soil behind retaining wall typically slopes towards the wall. This causes surface water to move in the direction of the wall, which leads to accumulation. Grading can be used to reduce the amount of water directed towards the wall. Proper grading will minimize the amount of water that will be directed towards the wall. A backfill made up of cohesionless granular materials will allow the water to penetrate the soil rather than building up above or within it. Thus the backfill material should have proper gradation as poor backfill material may swells and increases pressure on wall.

Objectives of the Study

- To determine particle size distribution of different cohesionless soils.
- To determine shear strength parameters of different cohesionless soils.
- To determine active earth pressure behind retaining wall by different theories.
- To suggest suitable cohesionless soil for backfill.

II. Materials Used For Study

2.1 Natural Sand

In this study, the locally available natural sand sample was collected from one of the construction site from Ravet, Pimpri Chinchwad Municipal Corporation. The experimental investigation on the natural sand was done to understand the index properties of the collected sand sample. On the collected sand sample natural sand was carried out tests like sieve analysis, specific gravity were carried out. From the results of sieve analysis we obtained two types of sand which are poorly graded sand and well graded sand.

Fig. 2.1 Natural Sand Well Graded

Fig. 2.2 Natural Sand Poorly Graded

2.2 Crusher Sand

Crushed sand sample was collected from the construction site going on in PCMC area. The experimental investigation on the crushed sand was done to understand the index properties of the collected sand sample. On the collected sand sample tests like sieve analysis, specific gravity were carried out. From the results of sieve analysis we obtained well graded sand.

Fig. 2.3 Crusher Sand

2.3 C- ϕ Soil (Murrum)

This soil sample was collected from the construction of retaining wall at Bhakti Shakti Chowk, PCMC. Same tests were carried out and the results obtained concluded the sample as well graded soil.

Fig. 2.4 C- ϕ Soil Murrum

III. Experimental Investigation

- **Specific gravity IS 2720 (Part- II) 1980**: The specific gravity of all the samples is measured by pycnometers per IS 2720 (Part II).

Observation table:

Table 3.1 Specific gravity

Sr. No	Weight	Sample 1 (Well graded sand)	Sample 2 (Poorly graded sand)	Sample 3 (Crushed sand)	Sample 4 (C-ϕ Soil)
1.	W1	704	702	703	702
2.	W2	1238	1233	1236	1143
3.	W3	2018	2021	2039	1942
4.	W4	1688	1686	1690	1686

W1: Empty weight of pycnometer
W2: Pycnometer + Dry soil
W3: Pycnometer + Dry Soil + Water
W4: Pycnometer + Water
Specific Gravity =

Fig. 3.1 Pycnometer Bottle

3.2 Sieve Analysis IS 2720 Part IV: The sieve analysis is performed as per IS 2720 Part IV. A receiver is kept at the bottom and the lead is placed on the topmost sieve of the stack. This assembly is subjected to shaking for 10 minute with mechanical shaker.

Fig. 3.2 Sieve analysis

Sample 1: Natural Sand (Well graded):
Observation table:

Table 3.2 Sieve analysis

Sieve size in mm	Weight retained in gm	Cumulative retained in gm	Cumulative % retained	Percentage finer
4.75	186	186	18.6	81.4
2.36	148	334	33.4	66.6
1.18	475	809	80.9	19.1
0.6	125	934	93.4	6.6
0.3	46	980	98.0	2
0.15	11	991	99.1	0.9
0.075	7	998	99.8	0.2
Pan	2	1000	100	0
Total	1000			

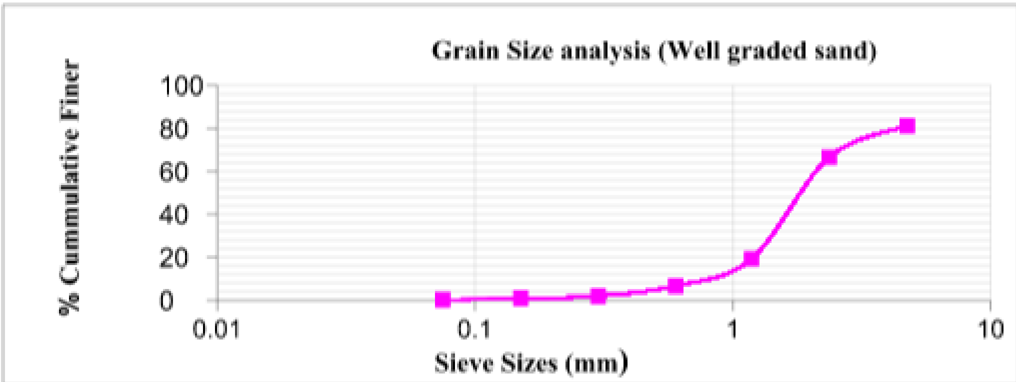

Fig. 3.3 Sieve Analysis (Well graded natural sand)

The results of the particle size analysis is presented in the form of graph as shown in fig. The D_{10} of soil sample is 3.79mm, D_{30} is 1.49mm and D_{60} is 2mm. The Cu and Cc are 2.53 and 1.43 respectively. Hence the soil sample is well graded.

Table 3.3 Results of sieve analysis

Grain size parameter	Natural Sand - 1	Natural Sand - 2	Crusher Sand	C - ϕ Soil
D_{10}	3.79	0.47	0.24	0.22
D_{30}	1.49	1.9	0.96	0.98
D_{60}	2.00	2.2	2.6	3.00
Cu	2.53	4.68	10.8	10.83
Cc	1.43	3.49	1.47	1.45
Gradation	Well Graded	Poorly Graded	Well Graded	Well Graded

3.3 Direct shear test: The fig. 5 shows direct shear test apparatus. The procedure for carrying out experiment is confirming to IS 2720 (Part II). The direct shear test is carried out on the all samples. The area of mould is 36 cm^2 and height is 5cm. test is conducted by keeping stain rate of 1.25mm/min. Also different normal stresses as 0.5, 1.0, 1.5, and 2.0 Kg/cm^2 and record the corresponding shear stress.

Fig. 3.4 Instrument setup for direct shear test

Fig. 3.5 Shear Box

Observation table

1) Natural Sand (Well Graded) :

Table 3.4 Results of DST

Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)
0.5	0.475
1.0	0.845
1.5	1.175
2.0	1.345

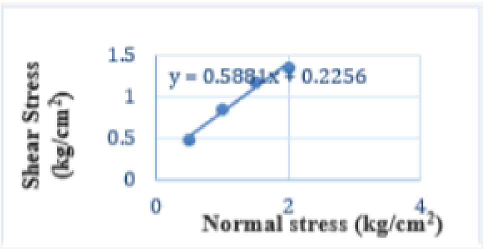

Fig. 3.6 Graph of Shear stress V/S Normal stress for natural sand

Result
Cohesion: 0.22 Kg/cm^2
Angle of internal friction (ϕ): 30.11˚

2) Natural Sand (Poorly Graded):

Table 3.5 Results of DST

Normal Stress (kg/cm^2)	Shear Stress (kg/cm^2)
0.5	0.523
1.0	0.741
1.5	1.264
2.0	1.466

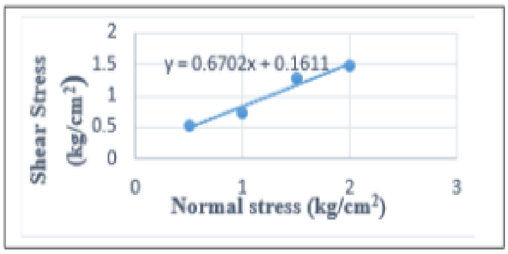

Fig. 3.7 Graph of Shear stress V/S Normal stress for natural sand

Result:
Cohesion: 0.16 Kg/cm^2
Angle of internal friction (ϕ): 33.82˚

3) Crusher sand:

Table 3.6 Results of DST

Normal Stress (kg/cm²)	Shear Stress (kg/cm²)
0.5	0.407
1.0	1.151
1.5	1.224
2.0	2.013

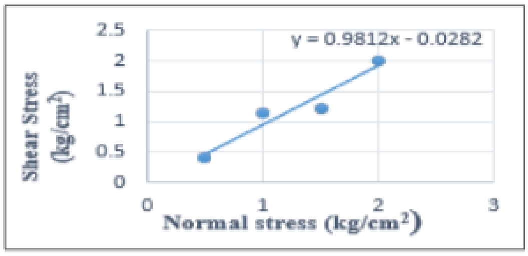

Fig.3.8 Graph of Shear stress V/S Normal stress for crusher sand

Result:
Cohesion: 0.02 Kg/cm^2
Angle of internal friction (ϕ): 44.45

4) C-ϕ soil:

Table 3.7 Results of DST

Normal Stress (kg/cm²)	Shear Stress (kg/cm²)
0.5	0.459
1.0	0.644
1.5	0.805
2.0	1.063

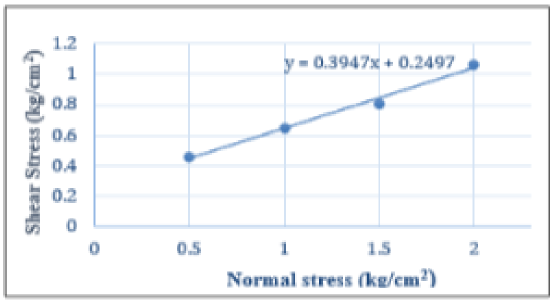

Fig.3.9 Graph of Shear stress V/S Normal stress for C-ϕ soil sand

Result:
Cohesion: 0.24 Kg/cm^2
Angle of internal friction (ϕ): 21.50˚

IV. Analysis of Active Earth Pressure

Analytical Method:

1) Rankine's theory

Table 4.1 Active Earth Pressure by Rankine's Theory

Sr. No.	**Type of soil**	**Angel of internal friction(ϕ)**	**Height of Wall (H)**	**Coefficient of active earth pressure (Ka)**	**Active earth pressure (Pa) in KN/m²**
1.	Natural sand Well Graded	30.11	0.8	0.331	2.032
2.	Natural Sand Poorly Graded	33.85	0.8	0.284	1.818
3.	Crusher Sand	44.85	0.8	0.172	1.189
4.	C- ϕ Soil (Murrum)	21.50	0.8	0.463	2.427

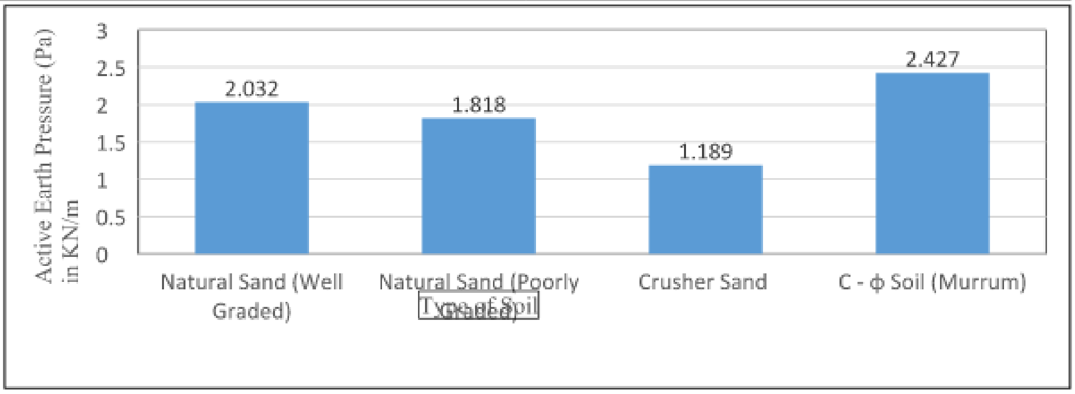

Fig.4.1 Type of Soil Vs Active Earth Pressure (Pa) in KN/m

2) Coulomb's Theory

Table 4.2 Active Earth Pressure by Coulomb's Theory

Sr.No	Type of Soil	Φ in Degree	α in Degree	δ in Degree	β in Degree	H in meter	Active Earth Pressure (Pa)KN/m^2
1.	Natural sand Well Graded	30.11	68	20.07	90	0.8	2.868
2.	Natural Sand Poorly Graded	33.82	70	22.55	90	0.8	2.654
3.	Crusher Sand	44.85	70	29.90	90	0.8	1.562
4.	C- ϕ Soil (Murrum)	21.50	68	14.33	90	0.8	3.154

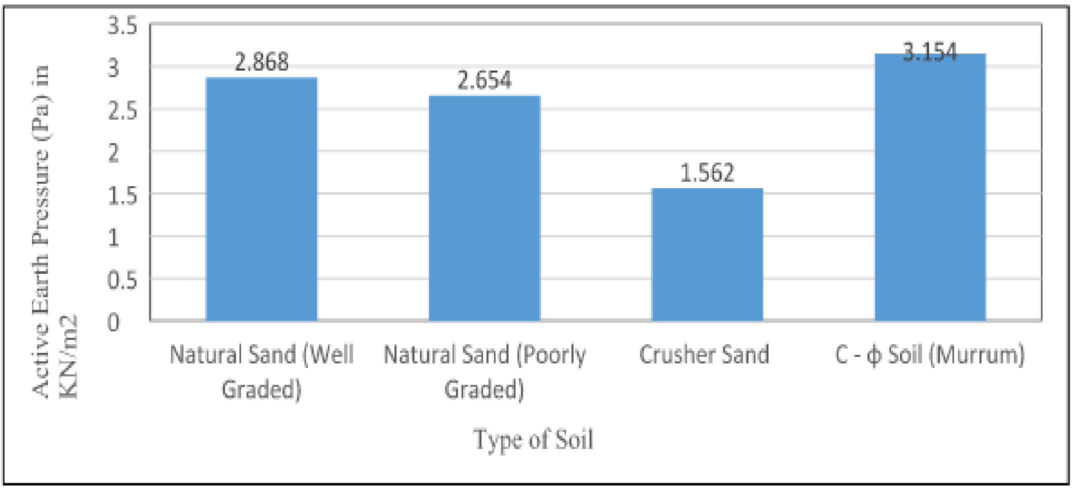

Fig. 4.2 Type of Soil Vs Active Earth Pressure (Pa) in KN/m

Graphical Method

There are two graphical methods for finding active earth pressure

A. Rehban's method

B. Culman's method

A. Rehbann's method:

1. Natural sand Well Graded:

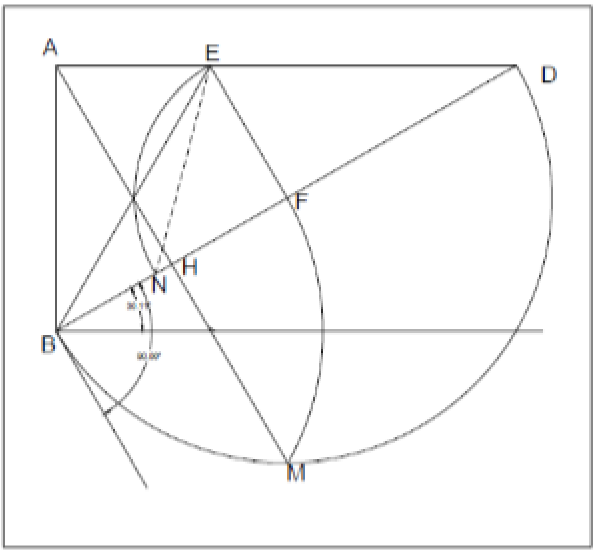

Fig.4.3 Rehbann's method for natural sand well Graded

P_{AE} = Area of Δ ENF x Density
P_{AE} = 1/2 x 0.45 x 0.46 x 19.19
P_{AE} = 1.986 KN/m^2

2. **Natural Sand Poorly Graded**:

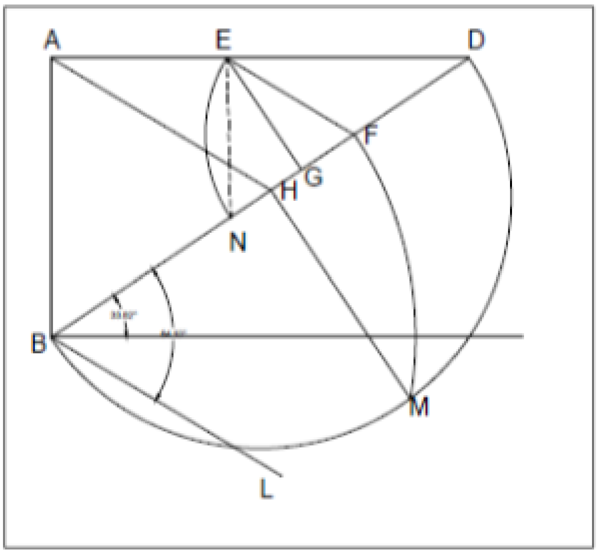

Fig.4.4 Rehbann's method for natural sand poorly graded

P_{AE} = Area of Δ ENF x Density
P_{AE} = 1/2 x 0.42 x 0.43 x 20.01
P_{AE} = 1.806 KN/m^2

3. Crusher Sand:

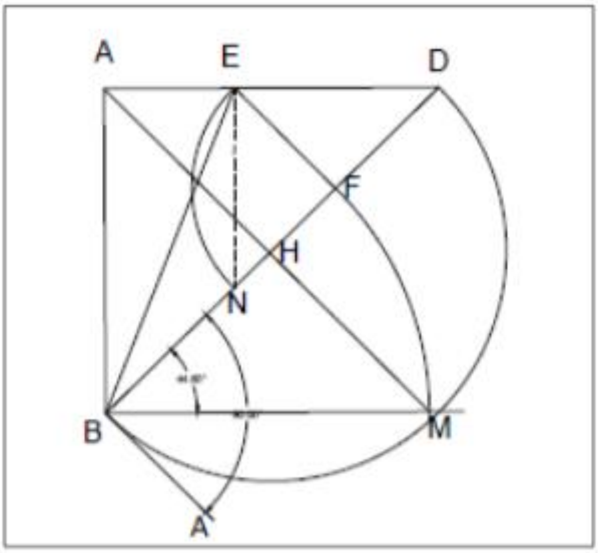

Fig.4.5 Rehbann's method for crusher sand

P_{AE} = Area of Δ ENF x Density
P_{AE} = 1/2 x 0.32 x 0.33 x 21.48
P_{AE} = 1.134 KN/m^2

4. C- ϕ Soil (Murrum):

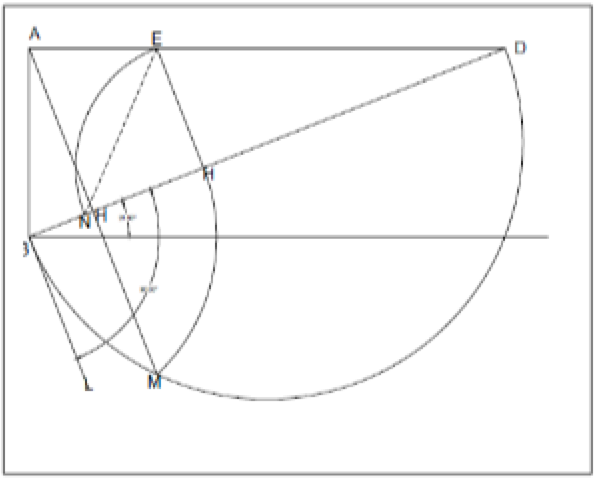

Fig.4.6 Rehbann's method for C- ϕ Soil (Murrum)

P_{AE} = Area of Δ ENF x Density
P_{AE} = 1/2 x 0.55 x 0.55 x 16.38
P_{AE} = 2.432 KN/m^2

Table 4.3 Active Earth Pressure by Coulomb's Theory

Sr. No	Type of Soil	Angel of internal friction(ϕ)	Height of Wall (H)	β in Degree	Ψ	Active Earth Pressure (Pa)KN/m^2
1.	Natural sand Well Graded	30.11	0.8	90	90	1.986
2.	Natural Sand Poorly Graded	33.82	0.8	90	90	1.806
3.	Crusher Sand	44.85	0.8	90	90	1.134
4.	C- ϕ Soil (Murrum)	21.50	0.8	90	90	2.432

Result: It is observed that, active earth pressure in crusher sand is minimum

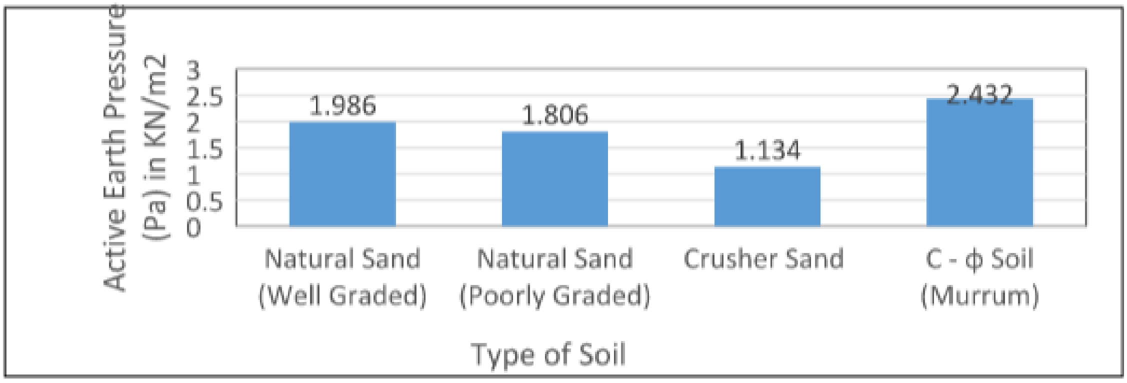

Fig.4.7 Type of Soil Vs Active Earth Pressure (Pa) in KN/m

B. Culaman's Theory :

1. Natural sand Well Graded:

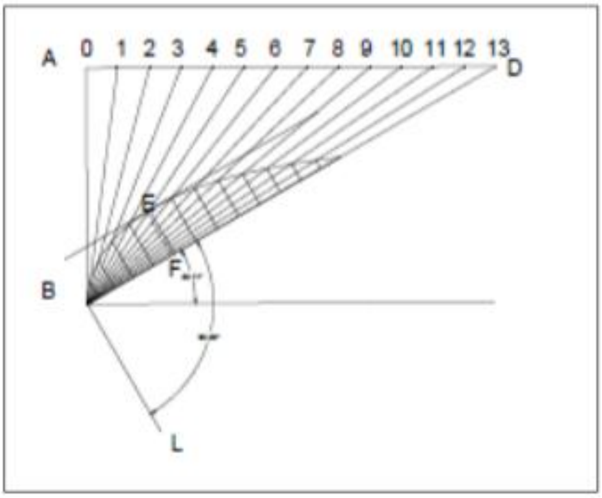

Fig.4.8 Culmann's method for Natural sand well Graded

P_{AE} = Length of EF x Scale
P_{AE} = 1.92 x 1
P_{AE} = 1.92 KN/m^2

2. Natural Sand Poorly Graded:

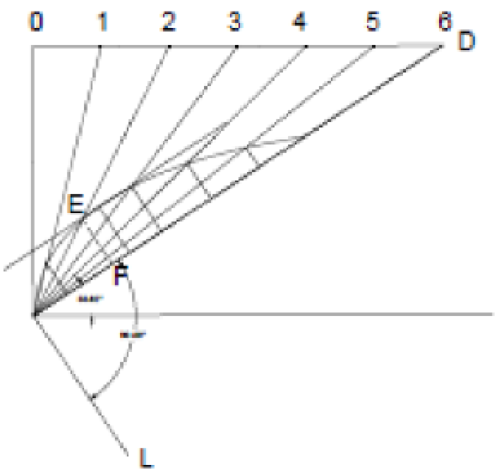

Fig.4.9 Culmann's method for Natural sand poorly Graded

P_{AE} = Length of EF x Scale
P_{AE} = 1.40 KN/m^2

3. Crusher Sand:

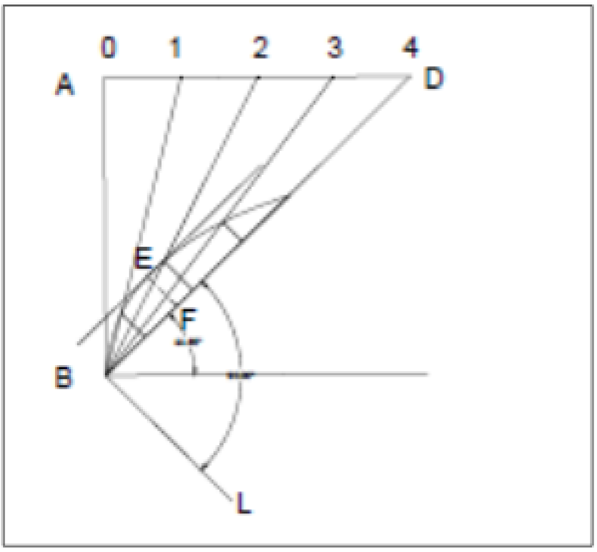

Fig.4.10 Culmann's method for Crusher Sand

P_{AE} = Length of EF x Scale
P_{AE} = 1.200 KN/m^2

4. C- ϕ Soil (Murrum):

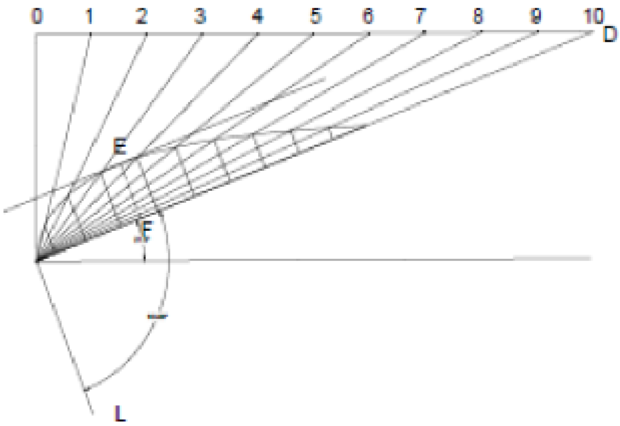

Fig.4.11 Culmann's method for C- ϕ Soil

P_{AE} = Length of EF x Scale
P_{AE} = 2.410 KN/m^2

1. Culaman's Theory :

Table 4.4 Active Earth Pressure by Culaman's Theory

Sr. No	Type of Soil	Angel of internal friction(ϕ)	Height of Wall (H)	β in Degree	Ψ	Active Earth Pressure (Pa)KN/m^2
1.	Natural sand Well Graded	30.11	0.8	90	90	1.920
2.	Natural Sand Poorly Graded	33.82	0.8	90	90	1.400
3.	Crusher Sand	44.85	0.8	90	90	1.200
4.	C- ϕ Soil (Murrum)	21.50	0.8	90	90	2.410

Result: It is observed that, active earth pressure in crusher sand is minimum

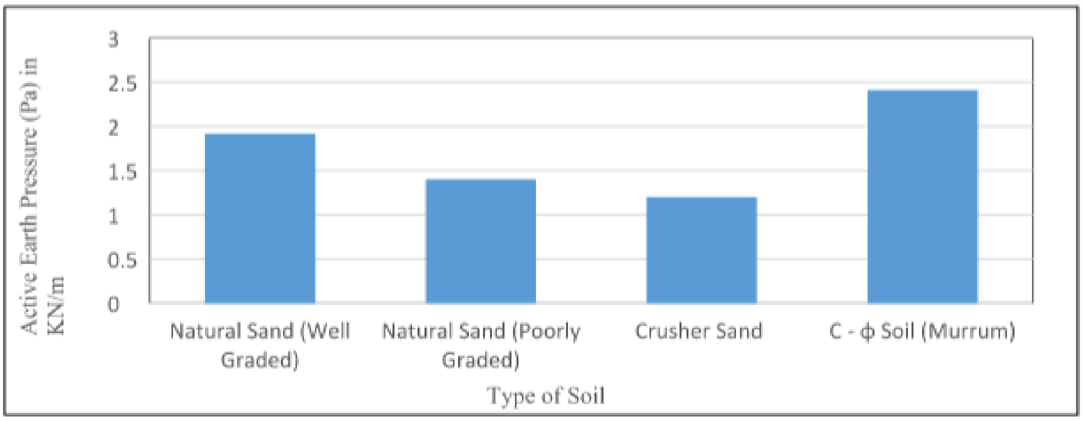

Fig.4.12 Type of Soil Vs Active Earth Pressure

V. Results and Discussions

Table 5.1 Comparison of active earth pressure for different soil and by different methods

Sr.No	Type of Soil	Angel of internal friction(ϕ)	Ht of Wall (H)	Active Earth Pressure KN/m			
				Rankine's	Coulomb's	Rehbann's	Culmann's
1.	Natural sand Well Graded	30.11	0.8	2.03	2.032	1.986	1.92
2.	Natural Sand Poorly Graded	33.82	0.8	1.82	1.794	1.806	1.140
3.	Crusher Sand	44.85	0.8	1.19	1.174	1.134	1.200
4.	C- ϕ Soil (Murrum)	21.50	0.8	2.43	2.400	2.432	2.410

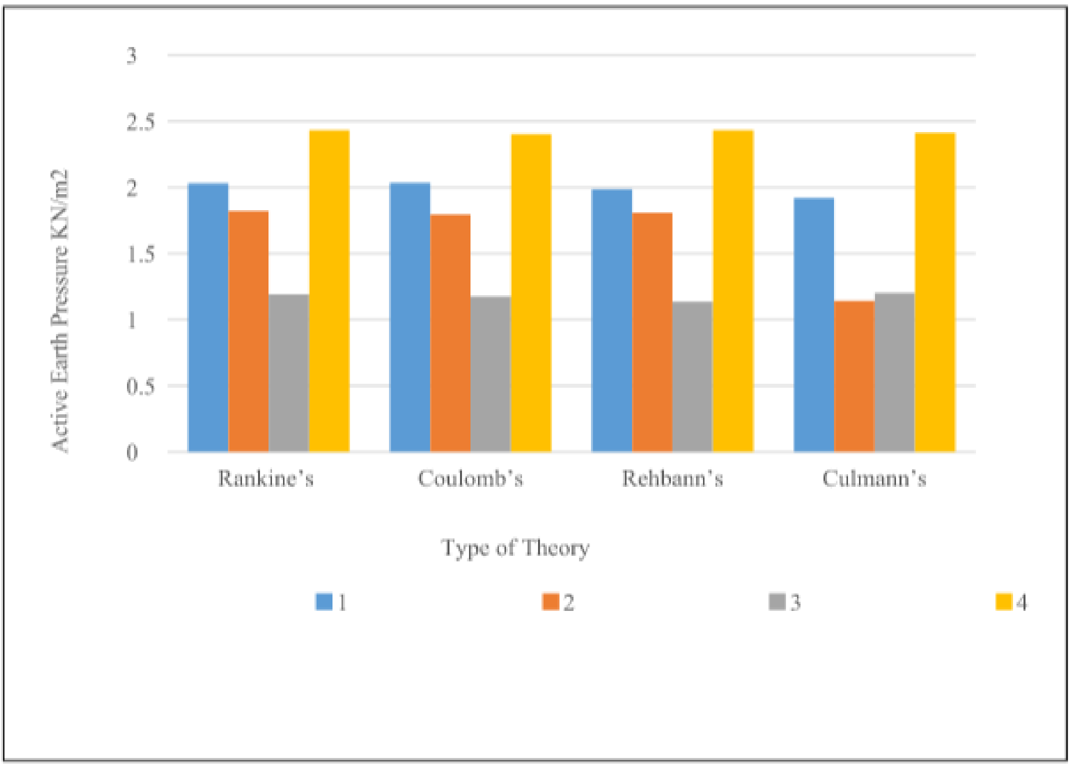

Fig.5.1 Active Earth pressure of different soils by different methods

VI. Conclusions

Based on results obtained from laboratory experiments, study and analysis of various earth pressure theories made for various cohesionless soil, the following conclusions are made:

1. The behavior of soil under external loads depends mainly on the gradation. This characteristics of soil can have a significant effect on its engineering properties. Thus it can be stated that for backfill the cohesionless soil is suitable and having proper gradation is very important.
2. With proper gradation maximum shear strength and angle of internal friction increases. The response of maximum shear strength is higher in graded particle as compare to uniform particle which is evident of the results obtained from various active earth pressure theories.
3. The results of direct shear test shows that the angle of internal friction is dependent on gradation.
4. The results from direct shear test were analyzed, and it is seen that active earth pressure is minimum in crusher sand.
5. It can be concluded that active earth pressure is 46% lesser in crusher sand as compared to active earth pressure of c- ϕ soil.
6. Active earth pressure is maximum for c-ϕ soil and minimum when crusher sand is used as a backfill, whereas natural sand shows intermediate values of active earth pressure in between crusher sand and c-ϕ soil.

Acknowledgement

We take this opportunity to thank Mr. S. P. Banne, our Project guide who has been a constant source of inspiration and also took keen interest in every step of the project development. We are grateful for their encouragement in shaping the idea and important suggestions in making it a reality. Again we take the opportunity to express our gratitude to Dr. S. T. Mali for the valuable guidance and for providing lab facilities as the H.O.D of Civil Department, PCCoE.

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