DETERMNATION OF BEARING CAPACITY OF BLACK COTTON SOIL REINFORCED WITH GRANULAR PILE USING PLAXIS 2D

ARUN PAUL

PG SCHOLAR

DEPARTMENT OF CIVIL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

NEW DELHI

INDIA

ABSTRACT

Soil stabilization is a process that improves physical soil characters such as increased shear resistance; load capacity etc can be done by compacting or adding appropriate additives such as cement, lime, and waste materials such as ashes flying, foci, etc. Techniques like using stone columns or granular piles within expansive soil layers are getting popular and effective now a days. Different researchers have also observed that soil strength on wetting can be improved significantly by use of granular piles. The load carrying capacity can be improved greatly depending on the initial consistency of the soil as well as the basic characteristics of that expansive soil. Further in this paper it is found that by using granular piles, the expansiveness can also be greatly reduced for black cotton soil and bearing capacity can be enhanced. In this paper, we are going to find out the improvement of bearing capacity of the black cotton soil by reinforcing it with granular pile with the help of Plaxis2D V8.2 software and load settlement analysis is also done with help of this.

KEYWORDS: *PLAXIS 2D, Granular pile, Settlement, Bearing capacity, Black Cotton soil.*

1. INTRODUCTION

Soil stabilization means the development of stability or bearing power of the soil by the use of controlled compaction, proportioning and the addition of appropriate admixture or stabilizers. Major soil deposits in many regions in India is Black Cotton Soils which are very fertile and suitable for agriculture but not good for construction of Civil Engineering Structures because of its low Bearing Capacity and severe shrink-swell process which results in growth of cracks. Hence, a great range of ground development techniques such as soil stabilization and reinforcement are needed to be engaged to improve the behavior of soil, thereby enhancing the consistency of construction.

The soil classification gives valuable information regarding engineering properties such as permeability, strength, expansivity, etc. The soils are classified based on particle size distribution and consistency limits. There are two broad classes of soils namely coarse grain soils and fine grain soils. Coarse grains soils contain gravels while fine grain soils contain silt and sand. Coarse soils or Granular soils have low plasticity to non plasticity and are generally less problematic. However, fine sands and silty sands or loose deposits of sands pose problem. The phenomenon of liquefaction is observed in fine sands where water table is near to the ground surface. Among the clayey soil the black cotton soil is considered as the most problematic as it has tendency to swell and shrink due to seasonal moisture variation. In India about one-fifth of the area is covered by expansive soil. The soil behaves like a soft soil under wet/saturated condition. As a result of wetting and drying process, vertical movement takes place in the soil mass leading to failure of structure, in the form of settlement, heavy depression, cracking and unevenness.

Other type of clay which is considered problematic is dispersive clay. These are mostly found as alluvial clays in the form of slow wash, lake bed deposits and are easily erodible. They are not generally identified by standard

laboratory tests such as index, grain size analysis etc. It is therefore concluded that nearly are types of soils may pose problem depending on different combination of working conditions and therefore may need improvement. The soil properties related to strength, settlement, drainage etc. need to be tailored to suit the situation in the field. A wide range of soil improvement techniques are available which may be suitable to a particular type of soil or working condition. Depending upon the loading conditions and nature of soil, a suitable technique which is also economical needs to be adopted.
In the next few paragraphs we will basically observe and discuss different soil stabilization techniques that are applicable for black cotton soil or other expansive soils specially.

2.1 Methods of Soil Stabilization:

There are various materials in utilization for the stabilization of black cotton soils. Depending on the internal factor which describes the bonding between the soil and the stabilizer utilized, the stabilization or ground improvement techniques can be classified with respect to soil type. They are as follows-

A. FOR COHESIONLESS SOIL:

i) Dynamic Compaction
ii) Vibro Compaction
iii) Compaction by deep blasting
iv) Compaction by piles
v) Grouting
vi) Stone Columns

B. FOR COHESIVE SOIL:

i) Stone Columns
ii) Vertical drains
iii) In-situ deep mixing
iv) Vacuum dewatering
v) Soil stabilization by physical or chemical process

A. COHESIONLESS SOIL:

Dynamic compaction is one of the most popular and economical methods for ground improvement for granular soils. By using heavy dynamic loads, the void ratio is decreased and the soil is compacted.
The vibro-compaction technique is used for sandy soil to compact the soil strata using dynamic vibration. Up to 85% of relative density can be achieved for sandy soil by using this technique. Loose sand up to 30 meters can be densified by using this technique.
Also in case of granular soils, blast densification is suitable for large areas such as the site of the dam and is effective in saturated sands having very low clay content. The method increases the density of loose granular deposits, above or below the water table.
We can also use grouting technique in cohesionless soil type. A cement slurry or grout is injected into the soil strata and after hardening, the soil strata is stabilized and improved bearing capacity is shown.

B. COHESIVE SOIL:

Using stone columns within soft soil is a popular technique for stabilizing cohesive soil. The soil is excavated to make a cylindrical hole and granular material is filled in it to reduce the settlement of the soil strata. This technique can be used both in case of cohesive and cohesionless soil.
Vertical drains accelerate primary consolidation only as significant water movement is associated with it. Secondary consolidation causes only very small amount of water to drain from soil; Secondary settlement is not speeded up by vertical drains.
Prewetting and preloading method is very common. In cohesive soils, use of vertical drains and vacuum dewatering, the settlement process can be speeded up and the soil is stabilized much faster.

Soil stabiliZation techniques can be further classified into different chemical processes such as-

LIME STABILIZATION :

Generally clayey soils, moorum and other alluvial soils can be stabilized by using slaked lime or $Ca(OH)_2$. Different researchers have shown in their experimental studies that for effective stabilisation, a soil must have a fraction passing 425 micron sieve not less than 15 percent and Plasticity Index (PI) at least 10 percent. (Mathur et al. 2012)

CEMENT STABILIZAION :

Different researchers have observed that based on following criteria, cement stabilization can be useful in some kind of soil- (Mathur et al. 2012)

i) The 75 micron fraction should not be more than 60% in the soil.

ii) C_u should be at least more than 5 and preferably more than 10.

iii) The silty clay with higher percent of organic material present is suitable for cement stabilization.

iv) If micaceous soil is not suitable for this kind of stabilization.

NON CEMENTIOUS MATERIALS:

Some non cementious materials like quarry dust, kiln dust, rice husk etc. can also be used as stabilizing agents of expansive soils like black cotton soil. Researchers like (Sridharan et al. 2006) has observed that quarry dust can be used with advantage to improve the engineering properties of soils. There is considerable increase in dry density on addition of quarry dust with attendant decrease in the optimum moisture content (OMC).

CHEMICAL STABILIZATION:

Montmorillonite is the primary clay mineral in black cotton or any expansive soil. Different lab tests like chromatography, spectroscopy, X-ray diffraction, electron microscopy, and standard titration analysis are carried out to observe the structural element and the physical-chemical study is been done. Then different techniques of chemical stabilization is used for improvement of soil properties.

COHESIVE NON SWELLING LAYER:

Replacing expansive soil layer by cohesive/impermeable materials can be effective for stabilization of that particular soil. The shear strength of underlying layers can be greatly increased by increasing the thickness of the non swelling impervious layer. (Katti. 1979)

GEOSYNTHETIC MATERIAL:

Now a days, use of geosynthetic materials for construction of road pavements, dams, bridges, and other heavy structures has increased for construction on expansive soil. In case of black cotton soil also, natural or artificial geosynthetic materials, geonets or geotextile materials are commonly being used as a mode of easy way of soil stabilization.

GROUTING:

In case of peat soil, as well as cohesionless soil also, grouting can be a very effective technique for stabilization. Generally sodium silicate is used to inject into the underlying soil layer. According to (Huat et al. 2011), 2.5% of sodium silicate gives maximum strength to the soil. The mechanism of grouting in peat soil can be explained by following reactions-

Cement + water $\rightarrow$ C-S-H gel + $Ca(OH)_2$

$Na_2(SO_3) + Ca(OH)_2 \rightarrow Ca(SO_3) + 2Na(OH)$

2.2 USE OF STONE COLUMN:

- Applicable to both cohesive and cohesionless soil.
- Supports structures like dams, embankments, tanks and low rise structures.
- Soil's bearing capacity and strength is increased and settlement is reduced.
- By its use, liquefaction in soil can be avoided to great extent as pore water pressure is decreased.
- as it is mostly made of granular materials, even water drainage system through stone column is good.
- Shear modulus and friction angle of soil is greatly improved and also the slope stability is enhanced.

2.3 CONSTRUCTION METHODS:

Stone columns are constructed by basically two methods-

A. Vibro Compaction method
B. Vibro replacement method

A. VIBRO COMPACTION METHOD:

The main motto of this method is to provide compaction to generally coarse sand or gravel with not more than 15% silt present in it. This method helps the soil particles to rearrange in such a way that they get more densified than before and relative density is increased. A vibrating poker device consisting of a cylindrical steel shell with an interior electric or hydraulic motor carries out the Vibro-Flotation by piercing in the soil up to the specified depth. The fast moving poker device induces high friction angle while constructing a column and thus the construction ground gets more strength than before. Then the hole created by the water jets are filled up by gravel and crushed stones. The vibroflot acts and the surface is densified.

But the problem with this method is that in case of clayey or silty soil, the method is merely effective and that's why vibro replacement method is introduced.

B. VIBRO REPLACEMENT METHOD:

This method is widely used in case of cohesive soils and vibration for densifying the soil is not applied in this method. Soils like loess, marine soil and silty soils are treated in this method. The main advantage is its ability to work upto greater depth and speed of work. The method is classified in 3 types-

i) wet top feed
ii) dry top feed
iii) dry bottom feed

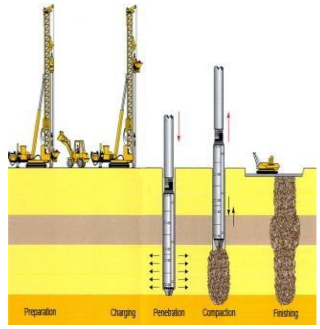
i) <u>Wet top feed:</u> It is used in case of medium to deep treatment of soil and mostly applicable for softer cohesive soils of shear strength 15-50 kPa. In this method, water forces through the head of a vibrator bit already mounted on the end of a drilling rig. After reaching the desired depth, stone backfill of size 12-75mm stones are added and it is densified mechanically or electrically. The main problem with this method is water supply and disposal.

Wet top feed (source- Goyal, D. et. al 2015)

ii) <u>Dry top feed:</u> Dry top feed method is similar to wet top feed & uses controlled air flush to aid the construction. Since, dry top feed does not use jetting & flushing water; it is much neater than the wet technique.

iii) <u>Dry bottom feed:</u> after this method is introduced, dry top feed method has been used much less. This method is also suitable for soft soil deposits. The main advantage of this method is that construction is possible even at congested places and placed with scarcity of water. This method can successfully treat grounds with un-drained shear well below 15-20 kPa. Penetration to required depth occurs through the combination of vibrations & downward force of the machine. Then the backfill is done with stones by using a bin that moves from the top to bottom head of the vibrator machine.

Dry bottom feed (source- Goyal, D. et. al 2015)



2. LITERATURE REVIEW

The literature review of the project consists of titles such as research work, parameter and result of different research works on change in various attributes of granular pile reinforced black cotton soil on circular footing-

Shahu & Reddy (2011) : The soil for experiment has strength (C_u)= 7-9 kpa, model tank was used of 300mm dia and 600 mm depth, model stone columns have diameter of 13mm and 25 mm and length of 100mm and 150mm respectively. Total no of columns used are 9, 13 and 21 and the area ratios 10%, 20% and 30% respectively.
The decrease in the settlement was much higher for the increase in the area ratio from 10-20 % than to that from 20-30%. The bending depends on the position of the column in the group. i.e. bending increases from centre of the column to the peripheral & to a corner of column.

Rao & Madhira (2010): Black cotton soil reinforced with model stone column of dia 800mm and depth 11m. Spacing is given as 1.6m, 2m and 2.5m c/c.
Results of 1.6m, 2.0m & 3.0m center to center spacing have shown an improvement of 100%, 25% and 3% resp. Effective spacing between SCs should be 2 to 3 times of column diamater.

Harish C. et. al (2016) : The model tests are conducted in a steel cylindrical tank of diameter 250 mm and height of 300mm, the small scale model footing tests are conducted on unreinforced and reinforced black cotton soil. Unreinforced tests are carried out and then reinforced with quarry dust column encasement are conducted.
It is seen that composition of 15% consisting stone dust and lime gives maximum strength. It is observed that the bearing capacity of 30mm diameter 300mm length and for 40mm settlement is higher.

Donovan Mujah et. al (2016) : Numerical modeling of consolidation behavior of peat soil reinforced with stone column is observed in this study. It is revealed in the study that the final settlement is dependent on the area replacement ratio of the soil strata. The analysis showed that if larger diameter column can be used, it tends to settle less and vice versa. Also in further studies with geosynthetic material wrapped stone column, best result is observed in case of a single layer reinforcement and also in case of stiffer geogrids, the bearing capacity increases.

Murugesan & Rajagopal (2008) : In this paper, study has been done on low plasticity clay with a test tank of dia 210mm and height 500mm. stone column is made up of granite chips and diff dia samples are used as dia 50mm, 75mm and 100mm. Geo synthetic material of different types like woven, non woven, soft grid with fine and coarse mesh are used.
The ordinary SCs have shown a clear catastrophic failure where as the encased SCs have shown elastic behavior with no noticable failure. The load carrying capacity had increased by 3- 5 folds. The column encased with Woven geo-textile was much stiffer than the non-woven and the soft grid. The capacity increased with increment in the stiffness of the encasement.

Ayadat et. al (2008) : In this study, kaolin clay is used of strength (q_u) = 35Kn/m^2. The model test tank dimension is 390mm dia and 520mm depth. Dry silica made stone column of dia 23mm and length 470mm is

used. Internal combined reinforcement of 1% steel, 1% aluminium and 1% steel is been used in model stone column.
In the loose sand, bearing ratio increased to 42% for steel, 37% for nylon and 60% for aluminium rods; whereas for dense sand, the increase was slightly lower at 30, 25 and 50%, respectively. The load capacity was increased by 38, 54 and 75% for single, double and triple meshes, respectively.

Kumar Rakesh & Jain P.K. (2015) : Tests were performed on fully penetrating single granular pile in unit cell tanks to investigate the improvement of load carrying capacity of randomly mixed fiber reinforced granular piles with s/d ratio as 3 and unconfined compressive strength of soil is 50kN/m2 . From the model tests it is found that the load carrying capacity increases with increase in fiber content and fiber length.
The test results showed that with increase of fibre content, the strength of granular pile also increases. At an optimum percentage of 1% fibre, the results are most desirable.

N. Vijay Kumar et. al (2017) : Estimation of bearing capacity of black cotton soil is been done using quarry dust and geotextile. Tests have been done by adding 5%, 10% and 15% of quarry dust respectively and placing geotextile layer at depth of 50mm, 100mm and 150mm respectively.
From the above discussion it is concluded that with the addition of 15%quarry dust for black cotton soil the C.B.R value is increased by 2,34% and by placing the geo textile at a depth of 50mm from the top of the soil surface the C.B.R value is increased by 4.18%.

Malarvizhi & Ilamparuthi (2007) : The analysis was done numerically and experimentally on soft clay embedded stone column. The study was carried out by varying L/D ratio of the column, stiffness of geogrid and angle of internal friction of the surrounding stone material.
From the empirical study it is found that bulging occurs effectively at the top 4D depth of the column. Also the stiffer the geogrid is, more effective it is to resist settlement. Also with increasing L/D ratio, the settlement decreases but after the value exceeds 10, there is not much effect on the settlement reduction. The study showed that the effective reduction in the stone column bed is 50% of the stone column bed for the identical conditions.

3. MATERIALS:

BLACK COTTON SOIL: Black cotton soil: Black cotton soils are found in extensive region of Deccan Trap in India. They are of variable thickness, underlain by black sticky material known as “black soil”. Black cotton soil when comes in contact with water it either swells or shrinks and resulting in moments to the structure which are generally not related to direct effect of loading. On account of its high volumetric changes it is not suitable for construction. It swells and shrinks excessively due to present of fine clay particles. Alternate swelling and shrinking of soil is responsible for differential settlement of structure so black cotton soil must be treated by using suitable admixtures or other measures to stabilize it.

Source: The soil was bought from a local dealer named “Kumar Minerals”. As per the seller, the sample consists of more than 96% of clay and silt combined. And rest is sand.

Fig 1- Test soil specimen

Montmorillonite: It is also called Smectite. The structural unit of the mineral is composed of two silica sheets and one alumina (gibbsite) sheet, 2:1 mineral. The octahedral sheet is sandwiched between two silica sheets with the tips of the tetrahedron combining with the hydroxyls of the octahedral sheet to form a single layer. The thickness of this layer is about 9.6 Ǻ and the dimensions in the other two directions are indefinite. Further Montmorillonite has the largest specific surface among major clay minerals. These factors mean that a large amount of water and other exchangeable ions can easily enter between the layers causing the layers to be separated. Because of this affinity for water, clay soils containing montmorillonite mineral are susceptible to large volume changes. They swell as the water gains entry into the lattice structure and shrinks if the water is removed because of some reason. In a moist state, montmorillonite is highly plastic and has little internal friction. Its excessive swelling capacity may seriously endanger the stability of overlying structures and road pavement.

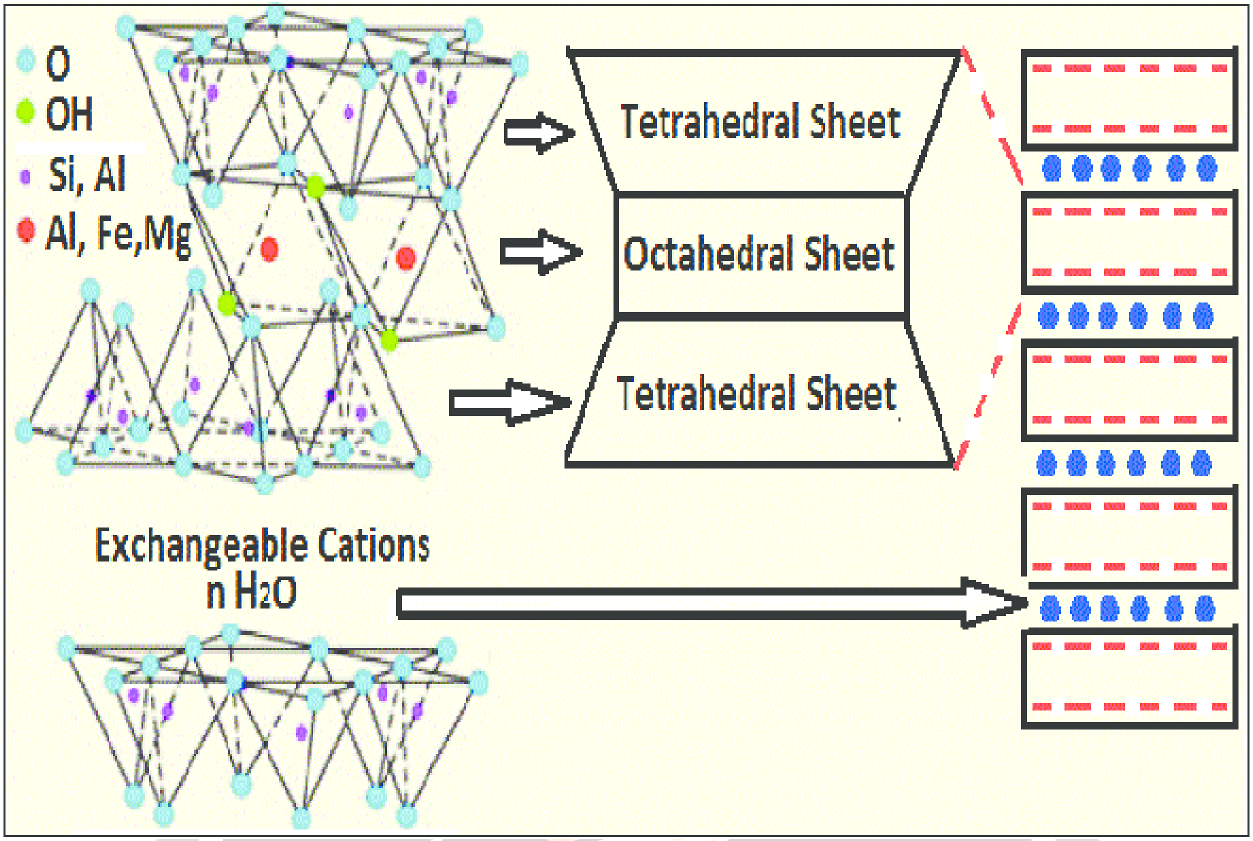


Fig 2: Montmorillonite structure (source- https://www.researchgate.net/figure/Montmorillonite-Structure-modified-from-Grim-1953_fig1_309550032)

STONE COLUMN/GANULAR PILE: (As per Harish. C et al. 2016)

For experimental procedure, model stone column is made from stone quarry dust passing through 2.36 mm sieve. The column is constructed by dry method. The enwrapped mild steel fabricated single and group columns of requisite length are placed in the bottom centre of the tank for single Column. Fabricated columns are removed carefully without disturbing the surrounding soil and keeping the cylindrical hole intact. As we could not carry out the physical tests, for the software design purpuse we will consider model granular pile of dia 0.3m and length of 10m and design accordingly.

CIRCULAR MODEL FOOTING: (As per Harish. C et al. 2016)

i) In the above mentioned paper, a model footing made of mild steel is used for lab testing for stone columns of different lengths and diameters as well as different D/B ratio where D denotes the depth of the test tank and B denotes the diameter of the test footing.

ii) But here just one model footing of dia 75mm is been used for software modeling purpose.

ii) The attributes are assigned in the software and test results were analyzed.

PLAXIS 2D SOFTWARE:

In this paper, we'll be using plaxis 2D software by Bentley. We are using PLAXIS 2D version 8.2 software readily available on internet. We'll use it to find out ultimate bearing capacity of black cotton soil in both reinforced and unreinforced condition. And observe the improvement in load bearing capacity due to use of granular pile.

4. EXPERIMENTAL STUDIES :

a. SPECIFIC GRAVITY OF THE SOIL SOLIDS :

The Specific gravity of the black cotton clay is determined using pycnometer as per IS 2720 (PART III/Sec I) 1980. Weigh a clean and dry pycnometer with lid (W_1) = 705g. Fill about one third of the bottle with oven dry soil and find the weight (W_2) = 925g. Fill the jar with water, ensure that air bubbles are trapped and weigh it (W_3) = 1720g. Empty the container and clean the bottle thoroughly. Fill the bottle completely with water and find its weight (W_4) = 1580g.

$$\text{Specific gravity} = \frac{(w2-w1)}{(w2-w1)-(w3-w4)} = \mathbf{2.75}$$

Fig 3: Pycnometer test

b. FREE SWELL TEST :

The swelling index of the clay specimen is determined as per IS 2720 (Part 40) 1985.

TEST PROCEDURE:

(i) Two no. of 10 g oven dried soil specimens passing through 425 micron IS sieve is taken.

(ii) Each soil specimen is poured in each of the two glass graduated cylinders of 100 ml. capacity.

(iii) Then one cylinder is filled with kerosene oil and the other with distilled water up to the 100 ml. mark.

(iv) It is to be stirred with a glass rod to remove entrapped air and allowed to settle for 24 hours.

(v) After completion of 24 hours the final volume of soils in each of the cylinder is read out.

Tabulation: 1

Volume of soil passing through 425 micron sieve (gm)	10
Volume of water after 24 hrs (cc)	14.5
Volume of kerosene after 24 hrs (cc)	10
Free swell index	45%

CALCULATION:

Free swell index (in percentage) : $\frac{Volume\ in\ water - volume\ in\ kerosene}{volume\ in\ kerosene} X\ 100$

$= \frac{14.5-10}{10} X\ 100$

= 45%

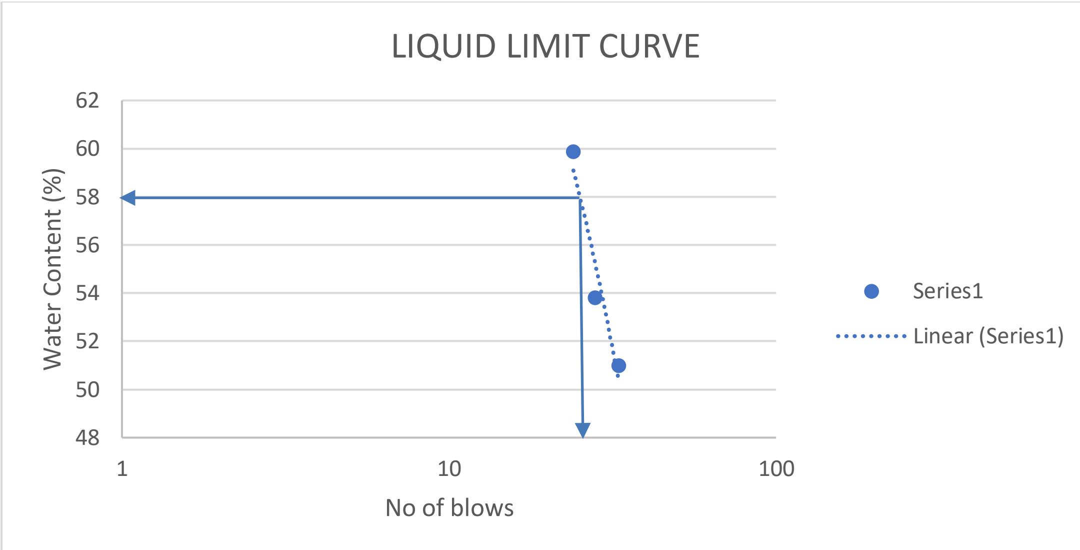
c. **Liquid Limit Test:**

Liquid limit is determined by Casagrande's Apparatus as per IS 2720 (Part 5) 1985.

Tabulation : 2

S. NO	Wt. of soil sample (g)	Water Content (%)	No of blows
1	125	53.80	28
2	125	51.00	33
3	125	59.88	24

Fig 4- Casagrande's Apparatus



From this curve, for 25 blows, the liquid limit is determined as **58%.**

d. Plastic Limit Determination:

Plastic limit is determined as per ASTM D4318.

Tabulation : 3

Container no	1	2	3
Wt. of container (W_1) gm	8.8	8.5	8.2
Wt. of container + Wet soil (W_2) gm	15.3	14.4	15.5
Wt. of container + dry soil	13.5	12.7	13.5
Water content (%)	28.2	23.61	32
Plastic limit (avg)	**28%**		

Plasticity index (Ip) : IP = WL– WP = 58 – 28 = **30**

So soil is a high plasticity clay. It is also determine from the IS plasticity chart As per the plasticity chart we obtained that the soil is above A- line and CH or OH group. So soil is highly clay or clay with high plasticity.

Liquid limit is = 58%

Plastic Limit = 28%

Plasticity index= 30%

Liquidity index :- LI = (W-PL)/(LL-PL) = (35-28)/(58-28) = **24%**

Fig 5 – Plastic limit test

e. Standard Proctor Test :

To determine the optimum moisture content (OMC) and maximum dry density of soil in laboratory standard proctor compaction was performed . It is defined as the minimum moisture content at which the soil specimen will become highly dense and obtains its maximum value of dry density in this soil was filled in three layers in proctor compacted mould and each layer was given 25 blows by proctor compaction hammer weighting 2.6 kg.
The test is done as per IS 2720 (Part-7) 1980.

Weight of mould +soil	Weight of soil	ρ_d	Υ_d	W_1	W_d	Water content (%)
3802	1642	1.61	15.79	21.21	19.36	9.34
3894	1734	1.70	16.67	16.73	14.67	14
3935	1775	1.74	17.07	12.11	10.22	18.4
3885	1725	1.69	16.58	16.1	13.14	22.5

Tabulation : 4

Sample Calculation:

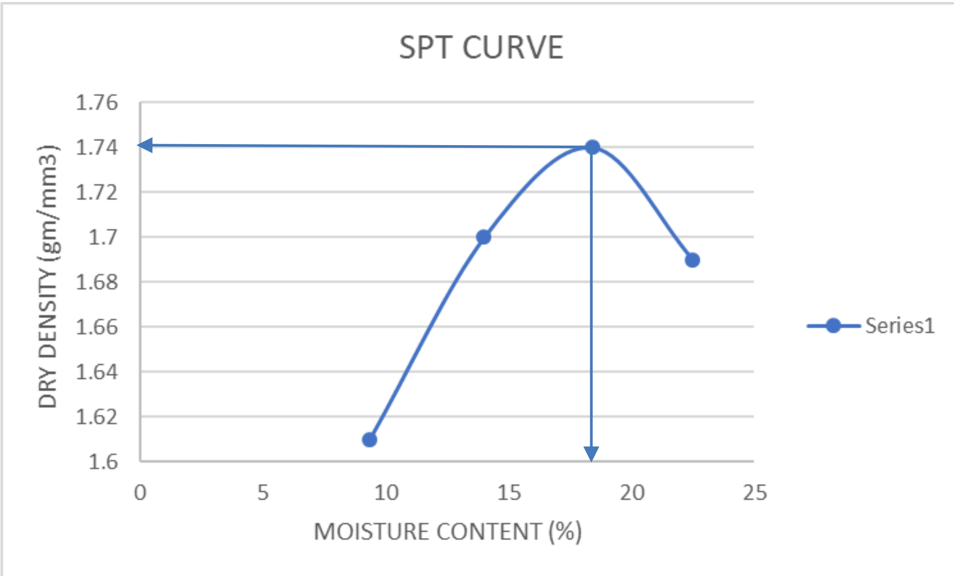
Wt. of empty mould= 2160gm

Volume of mould= 1020 mm^3

$$\rho_d = \frac{weight\ of\ soil}{volume\ of\ mould} = \frac{1642}{1020} = \mathbf{1.61\ gm/mm^3}$$

From the SPT graph we can find that optimum moisture content is **18.4%.**

Maximum dry density of the soil is **1.74 gm/mm^3.**



Graph 2: SPT graph

TABLE 5-Properties of Black Cotton Soil used in study(Used in Plaxis V8.2 software):

TEST PARAMETER	VALUE
Specific Gravity	2.75
Gravel content (as per material provider)	Nil
Sand content (%)(as per material provider)	4
Silt and clay content (%)(as per material provider)	96
Liquid limit (%)	58
Plastic limit (%)	28
Plasticity index (%)	30
Type of soil as per IS 1498-1970	CH, clay of high plasticity
OMC (%)	18.4
MDD (kg/m^3)	1.74
Field Moisture (%) (Source- Md. Khaja Moniuddin, 2015)	33.8
Poisson's ratio (Source- Md. Khaja Moniuddin, 2015)	0.4
Angle of internal friction(Source- Md. Khaja Moniuddin, 2015)	24
Cohesion(Source- Md. Khaja Moniuddin, 2015)	35.3
Unsaturated unit weight (calculated)	17.3 kN/m^3
Saturated unit weight (calculated)	22.07 kN/m^3
Modulus of elasticity (Source- Md. Khaja Moniuddin, 2015)	20000 kN/m^2

TABLE 6-Properties of model stone column used For study (Used in plaxis V8.2):

Test Parameter	Value
Specific Gravity (K., Rakesh et.al, 2015)	2.68
Poisson's ratio (K., Rakesh et.al, 2015)	0.3
Modulous of elasticity (Source- Dandagawhal., S. 2018)	19000 kN/m^2
Unsaturated unit weight (Calculated)	17.13 kN/m^3

Saturated unit weight(calculated)	22.48 kN/m^3
Field moisture content (%)(K., Rakesh et.al, 2015)	5% (prewetted)
Angle of internal friction (K., Rakesh et.al, 2015)	38.5
Dia of granular pile (Field assumption for software model)	0.3 m

5.6. SOFTWARE MODELING AND ANALYSIS:

As we could not carry out any physical tests on small scale model, data has been taken from different research works related to this topic and two models are presented by help of FEM analysis in PLAXIS 2D V8.2. The two models are- i) Settlement analysis of Unreinforced soil

ii)Load-Settlement analysis of granular pile reinforced soil.

Then bearing capacity of soil in each case is determined from the plaxis curves data by plotting the load-settlement curve and using tangent intersection method. Then these data is compared and evaluated for final conclusion.

i) SETTLEMENT ANALYSIS OF CIRCULAR FOOTING ON UNREINFORCED SOIL:

STEPS FOR DESIGN:

a) A new influence chart of 5x4 size is created by axissymmetry.
b) Using borehole feature, soil straitigraphy is created.
c) Material data set is assigned to soil layer.
d) The model is based on mohr-coulomb. No influence of water table is considered. Also material condition is drained.
e) Dilatency angle is taken zero.
f) Prescribed displacements are assigned and footing model is made by plate feature.
g) Data set is assigned to plate and corresponding load is also prescribed.
h) Mesh is generated. The calculation is done considering elasto plastic state.
i) Values of loads are modified in calculation phases.
j) Result output is generated and the force and displacement data is taken out to excel for further process.
k) The load-settlement graph is plotted and by tangent intersection method, maximum load q_u is found out and also load bearing capacity is calculated for further comparison.

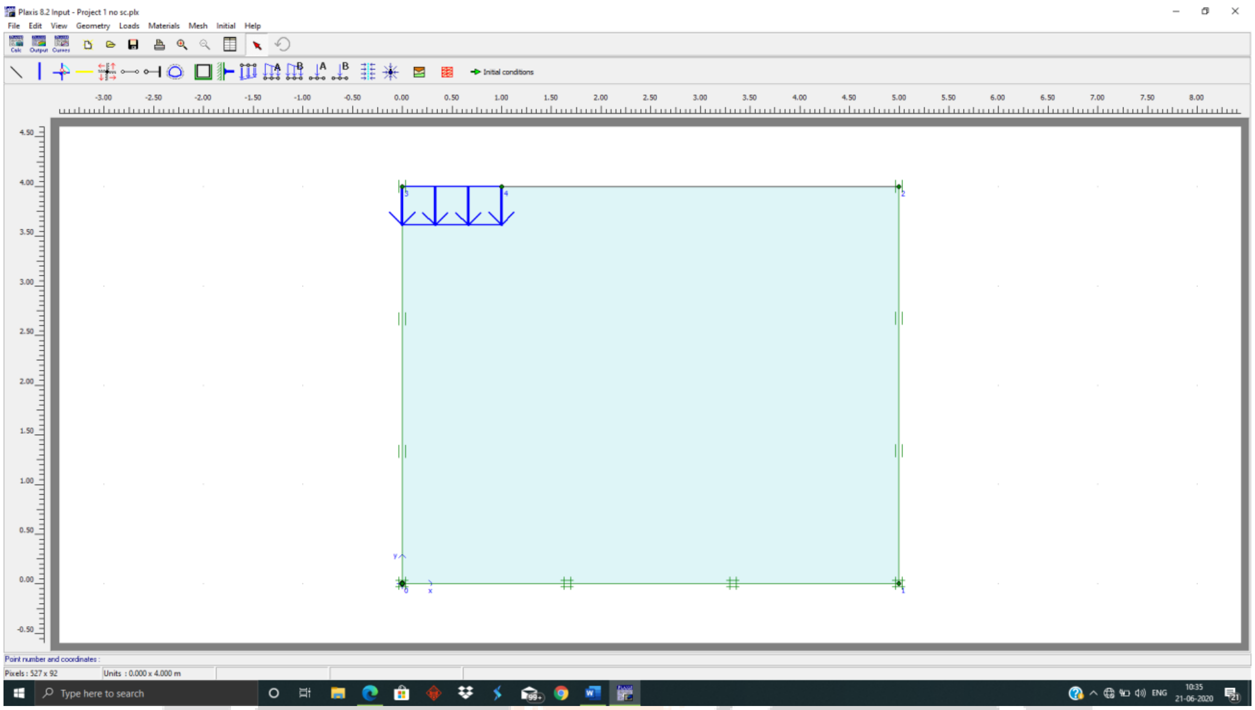


Fig 6- INFLUENCE CHART IS CREATED AND LOAD IS APPLIED

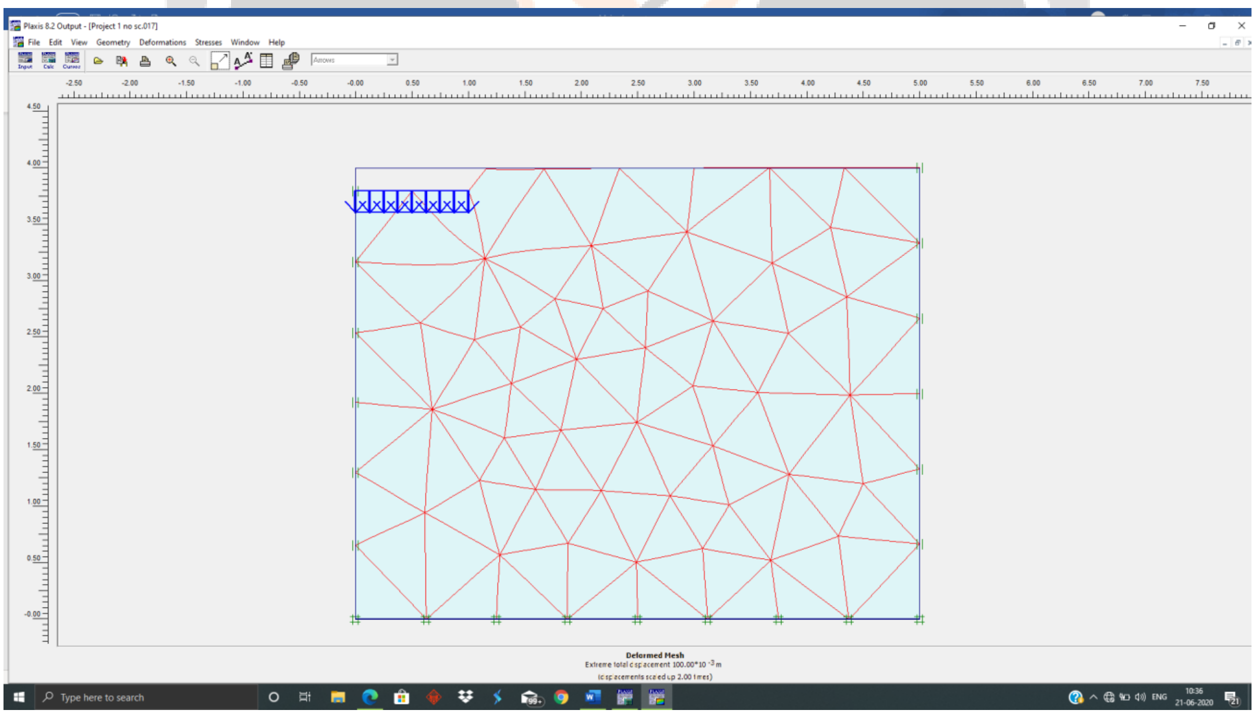


Fig 7- MESH GENERATED AFTER ASSIGNING ALL ATTRIBUTES

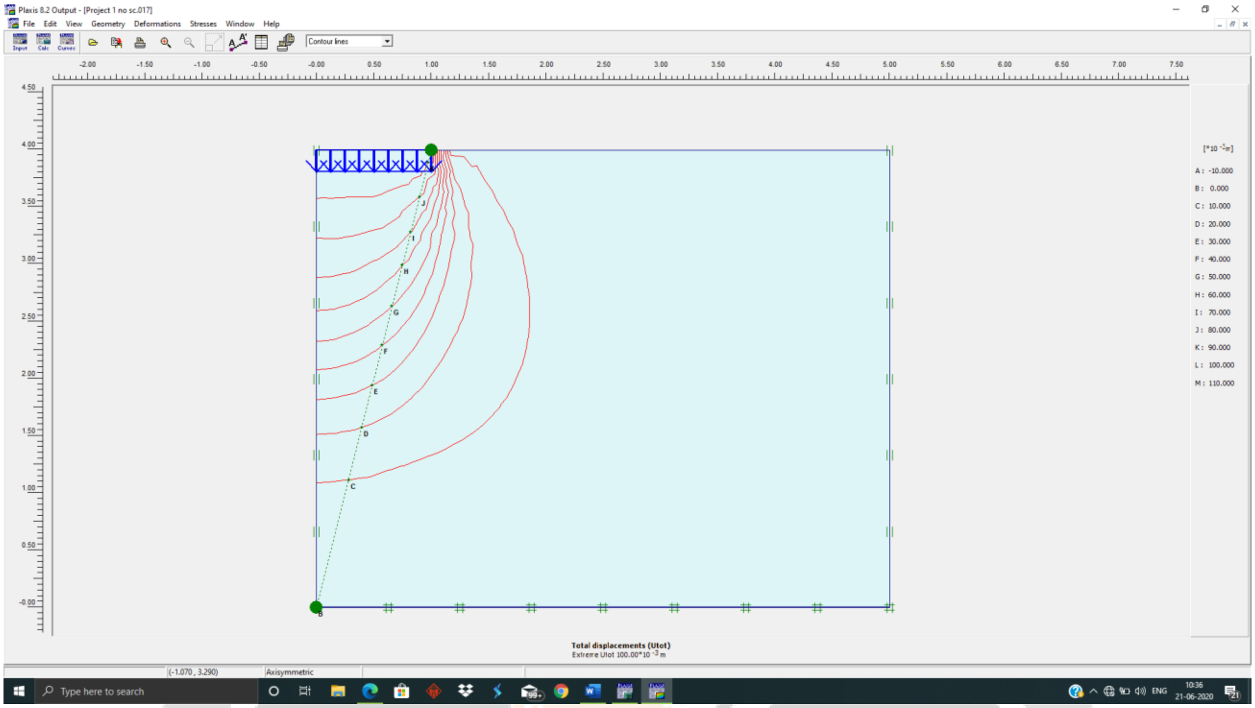


Fig 8- DIAGRAM OF STRESS DISTRIBUTION WITH RESPECT TO CONTOUR LINES AND ALSO THE PHREATIC LINE

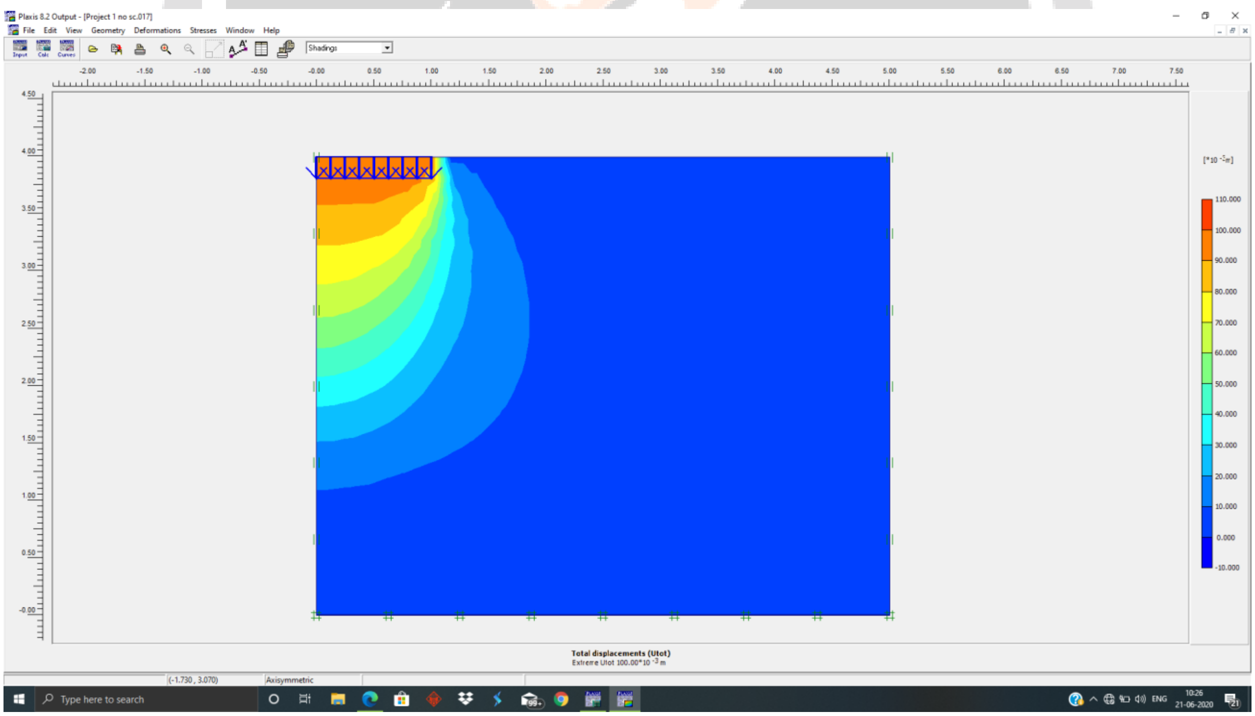


Fig 9- STRESS DIAGRAM AND INTENSITY OF STRESS IN DIFFERENT ZONES

i) SETTLEMENT ANALYSIS OF CIRCULAR FOOTING ON GRANULAR PILE REINFORCED SOIL:

STEPS FOR DESIGN:

a) First a 50x25 sized influence area with 15 nodal points is drawn in the PLAXIS 2D input software,

b) Plate command is selected and pile of 10m depth and 0.3m dia is inserted.

c) the designing is done as per Mohr coulomb,elasto plastic croteria and condition is drained.

d) After the granular pile is given all the required geometry, the soil properties are also properly assigned as mentioned in tables earlier.

e) After making soil layers and giving their input properties, the granular pile properties are assigned in the drawing like poisson's ratio, elastic modulus, unit weights etc.

f) At pile's nodal point, a point load is assigned and incremental value of -250kN is also assigned in phase generation module.

g) Then the mesh is generated and all the phase are moduled one by one and assigned.

h) The graound water table is also assigned.

i) After assigning, the model calculation is done and output is generated.

j) The force and displacement data is taken to microsoft excel and load-settlement graph is drawn. Then by tangent intersection method, the maximum load q_u is found out and corresponding load bearing capacity is calculated.

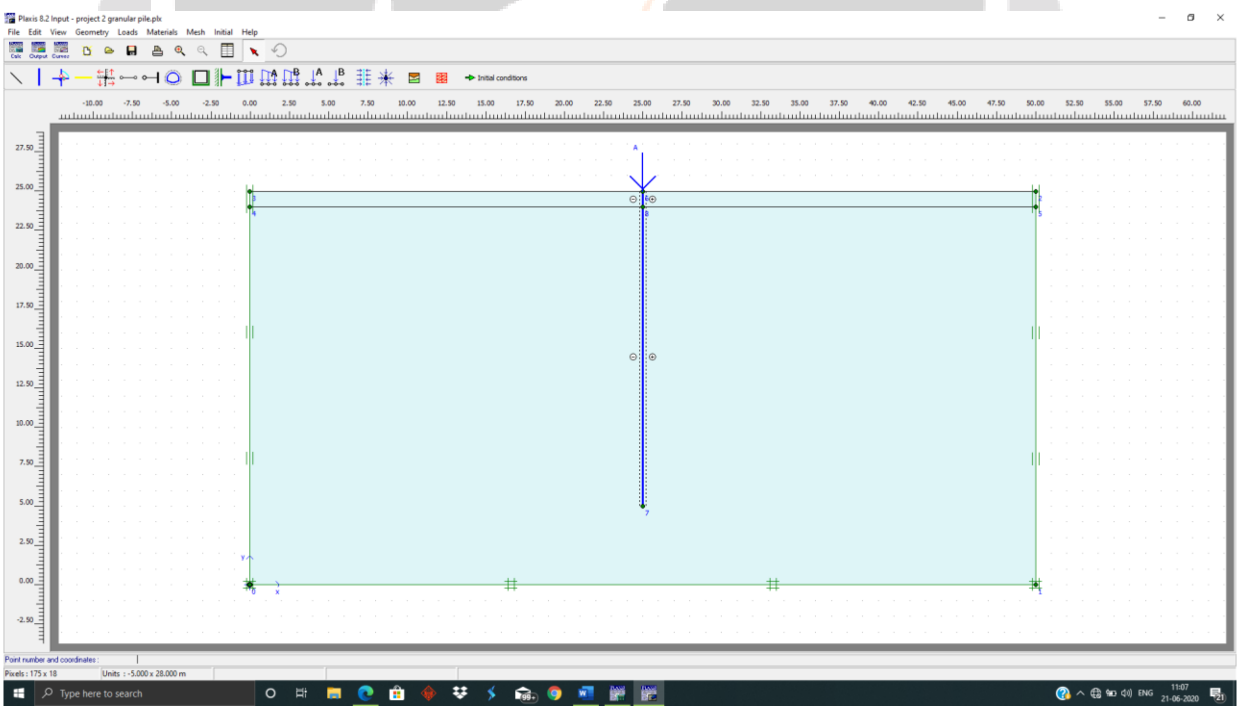


Fig 10- Influence chart created, grnaular pile assigned and loading also designated

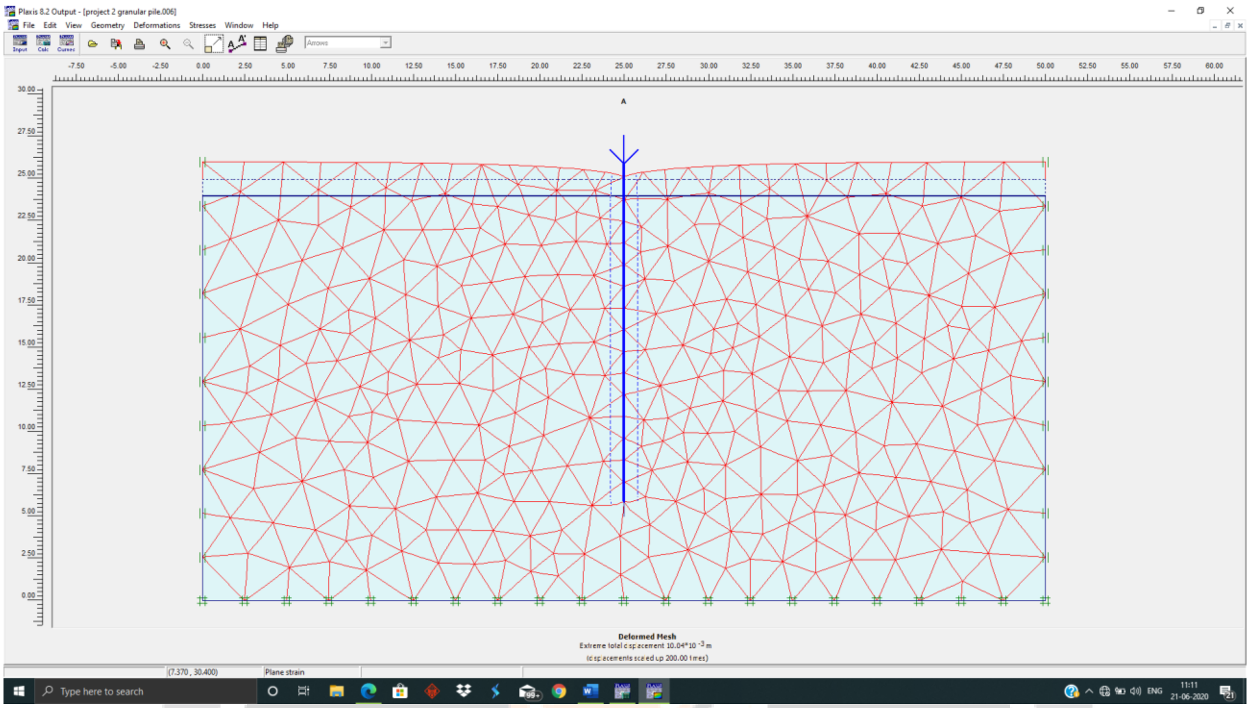


Fig 11- Mesh is generated and attributes of soil strata and granular pile have been assigned

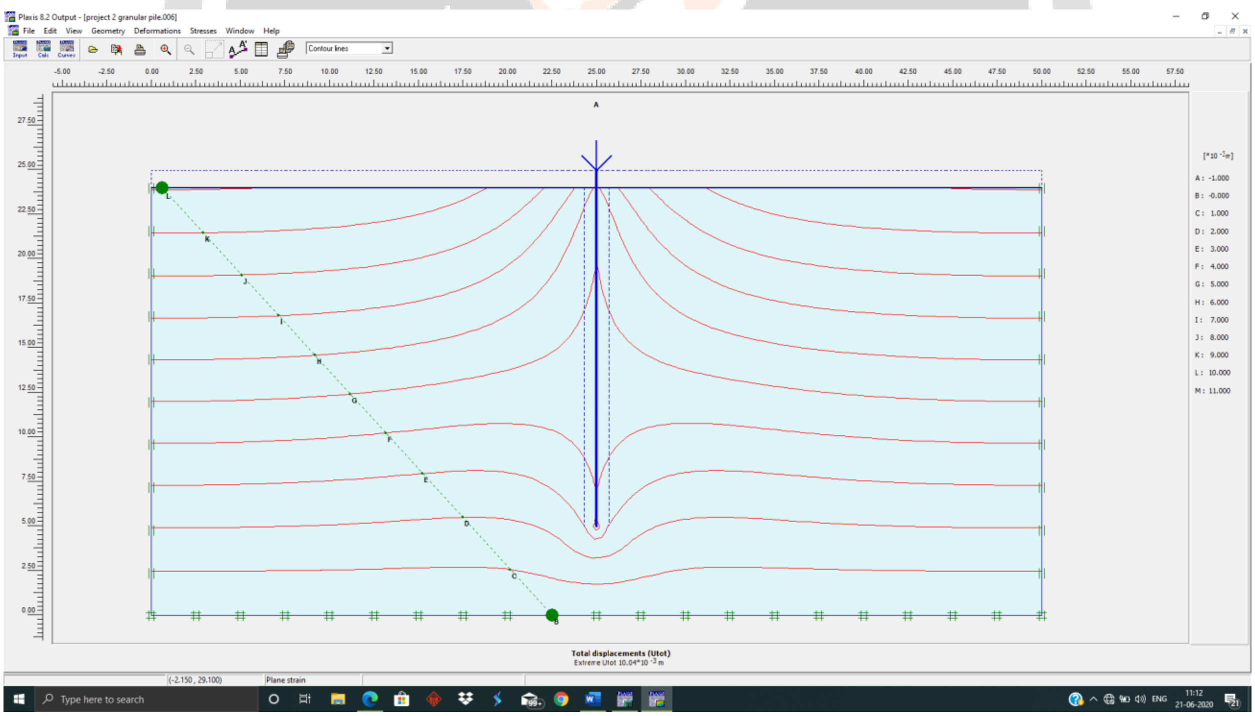


Fig 12- Contour diagram and position of phreatic line in the mode

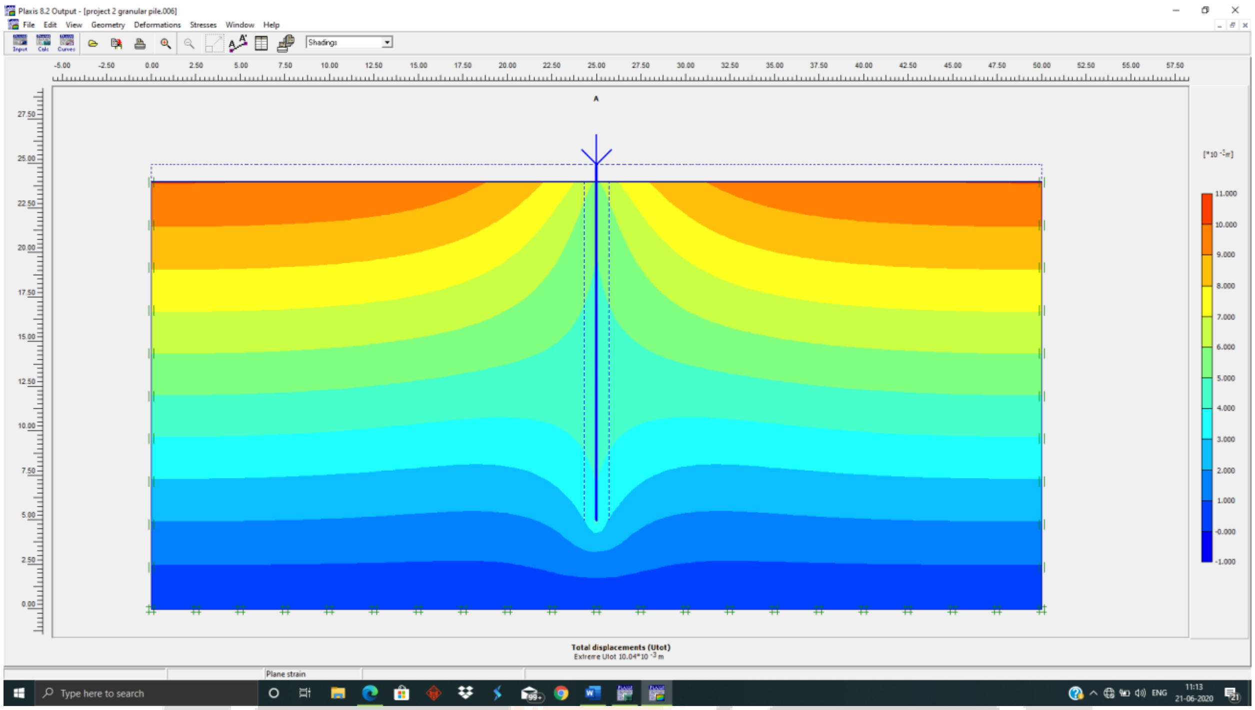


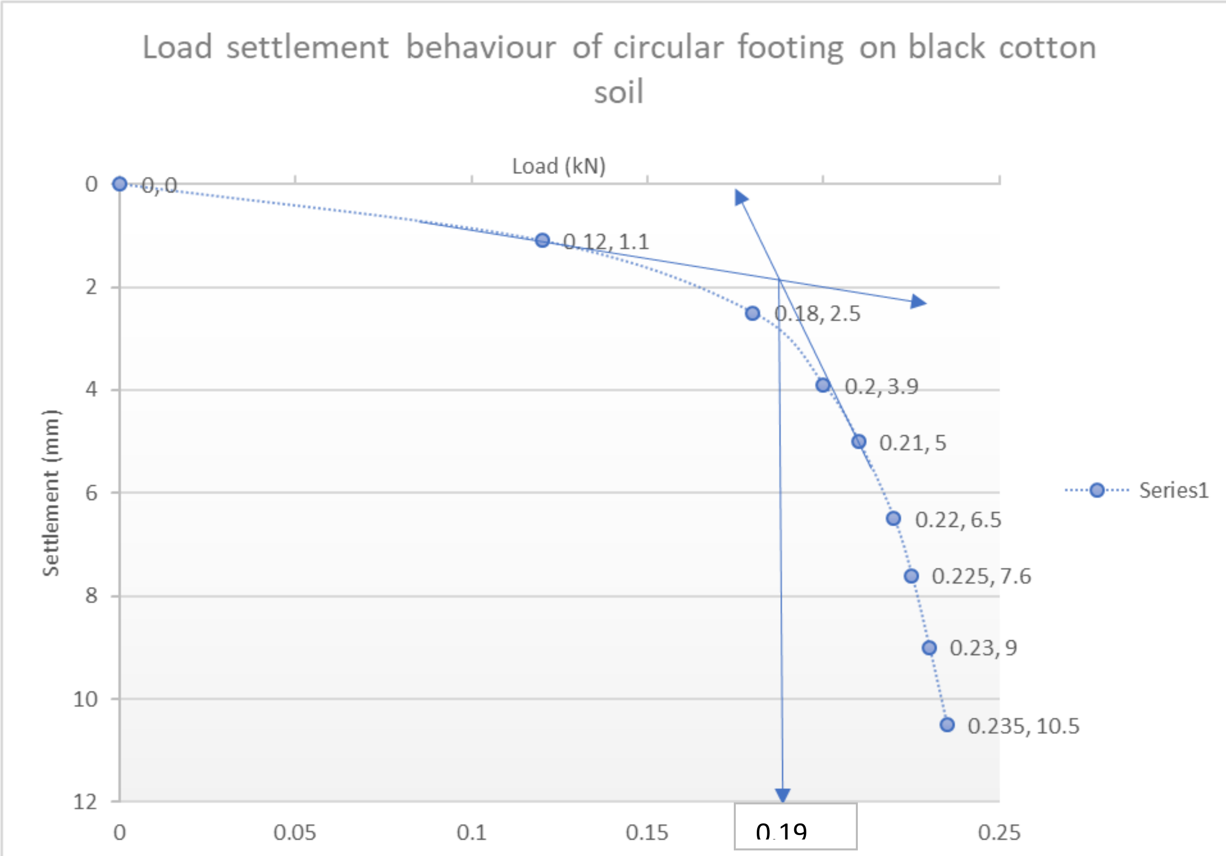
Fig 13- Stress distribution diagram and intensity of stress with respect to different zones

5. RESULTS AND DISCUSSION:

With the help of software modeling we have obtained load-displacement data for both reinforced and unreinforced soil cases. From the PLAXIS2D Curves data we have taken few no of data and they are represented in tabular form-

TABLE 7-Load-Displacement data in case of unreinforced soil

LOAD (kN)	Displacement (mm)
0	0
0.12	1.1
0.18	2.5
0.2	3.9
0.21	5
0.22	6.5
0.225	7.6
0.23	9
0.235	10.5

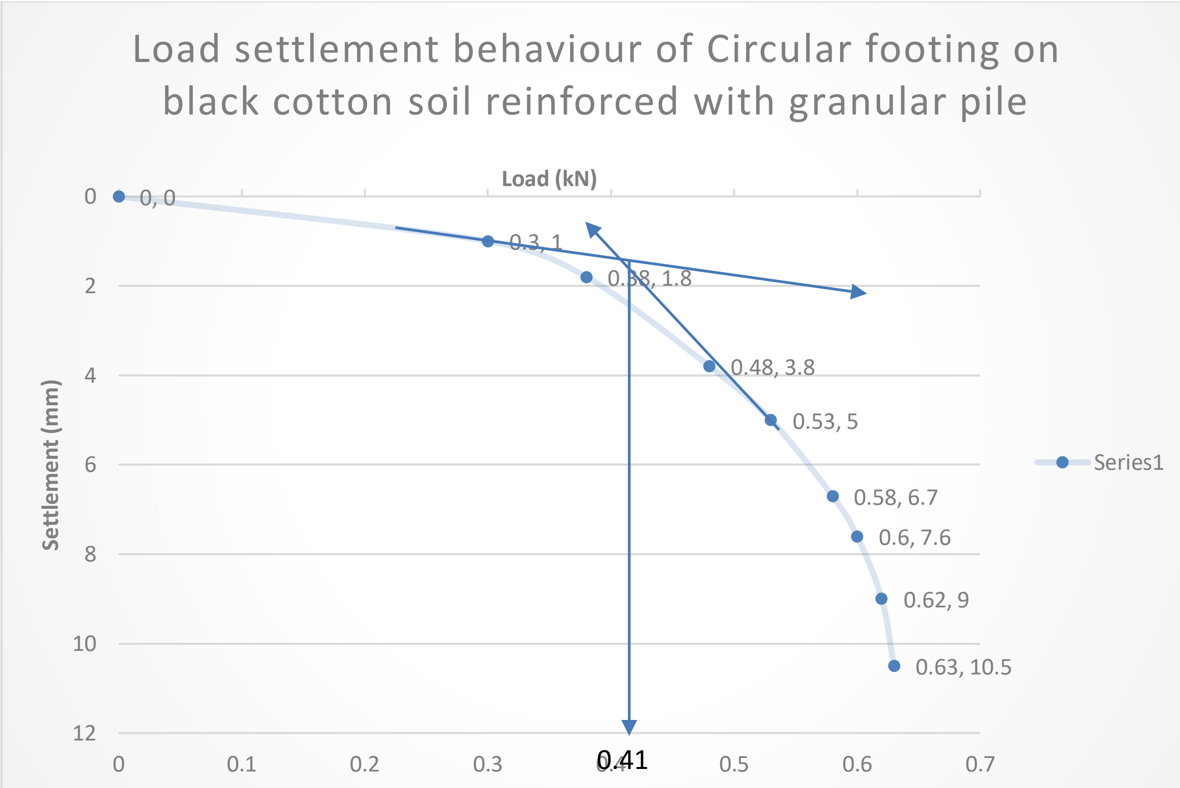


Graph 3: Load settlement of circular footing on black cotton soil

From the above graph, maximum load carried by the footing is determined as **0.19kN** by using tangent intersection method.

TABLE 8- Load-Displacement data for granular pile reinforced soil

LOAD (Kn)	DOSPLACEMENT (mm)
0	0
0.3	1
0.38	1.8
0.48	3.8
0.53	5
0.58	6.7
0.6	7.6
0.62	9
0.63	10.5



Graph 4: Load settlement behaviour of circular footing on granular pile reinforced black cotton soil

From the above graph, maximum load q_u is determined as **0.41kN** by tangent intersection method.

6.1 CALCULATION OF LOAD BEARING CAPACITY:

For the unreinforced soil, when the circular footing was used, the maximum load carried by the footing was found 0.19kN.

The base area of the footing of dia 75mm will be = $(22/7)*0.075^2 = 0.0176\ m^2$

So, load bearing capacity will be Q_u = (load/area)

= (0.19/0.0176)

= 10.8 kN/m^2 (approx)

Now, after the soil is reinforced with the granular pile of prescribed dimensions, the plaxis model has given maximum load carried by the footing as 0.41 kN.

Similarly by calculating, we can found out the load bearing capacity of the soil after being reinforced = (0.41/0.0176)

= 23.3 kN/m^2 (approx)

Thus, it can be said that after using the granular pile in the soil strata, the load bearing capacity has greatly improved from before which we can easily observe as the results show from the FEM analysis model in PLAXIS2D software. But there are some assumptions which might also have affected the results and in actual field conditions these results may differ a bit. These assumptions are-

i) Design has been done by following Mohr Coulomb criteria.
ii) The soil condition is considered drained and granular pile as plastic.
iii) The water level is considered as in the ground surface but if it is different, the results may differ.
iv) Dilatency angle is taken zero and also other soil conditions have been taken from different research papers which may differ in actual.
v) Field moisture content in determining saturated and unsaturated unit weight of column is been taken 5% which is water content by weight used for prewetting quarry dust. (Malarvizhi et.al 2007)

6. CONCLUSION:

i) Plaxis2D V8.2 has been used in this study to determine the bearing capacity of black cotton soil both in unreinforced and granular pile reinforced condition with help of Mohr Coulomb's failure criteria,

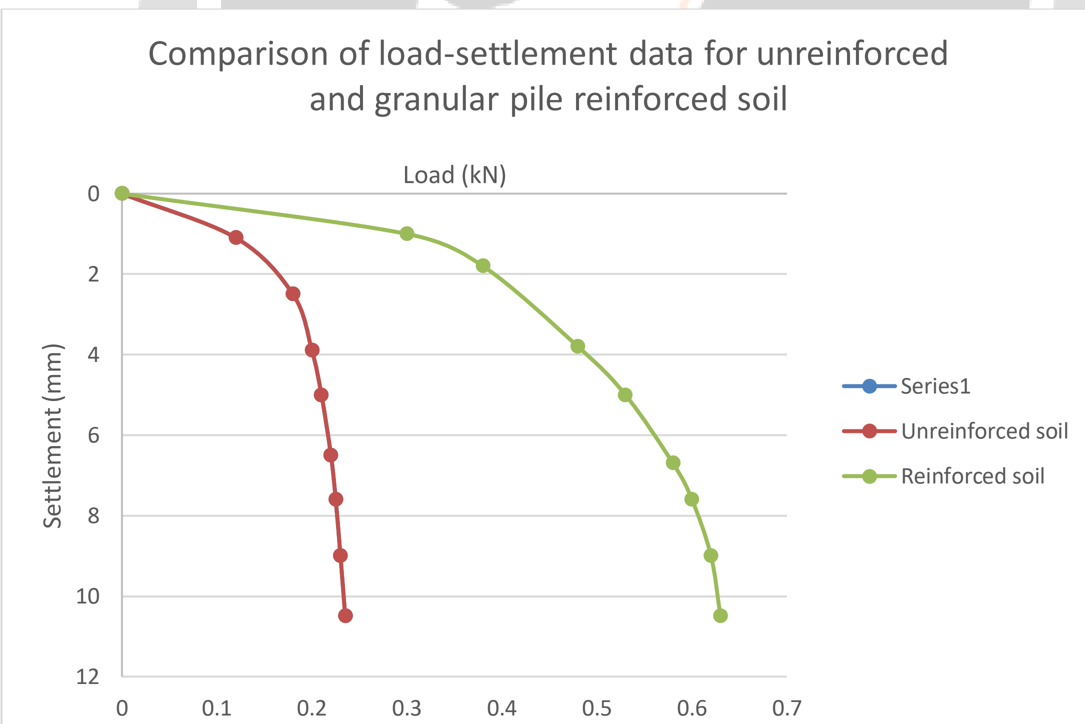
ii) The physical tests on model was not possible to carry out but still by use of FEM analysis in this software, we could come up with fairly reasonalble results that shows improvement of soil bearing capacity of black cotton soil when granular pile is used within soil strata.

iii) The ultimate load bearing capacity of the unreinforced soil was found out to be 10.8kN/m^2 and when granular pile is been encased within the soil, the load bearing capacity has been increased to 23.3 kN/m^2.

iv) So by software analysis only and without carring out any physical model tests, we have showed that by using granular piles i.e. stone column in black cotton soil, we can greatly improve the bearing capacity of the soil. In this case it has improved by approximately 116%.

v) Although there is always a chance of accuracy as many constraints were there and assumptions were taken. Yet we cannot overlook the importance of this software for FEM analysis of any kind of soil strata.

vi) Here is a comparative representation of load settlement curve in two cases-



Graph 5: Load settlement behaviour of circular footing on expansive soil (comparison)

7.1 Scope of furthur study:

i) This study is mainly based on plain strain condition and 2D model. But we can further analyze in 3D also and the need for 3D is detailed modeling and model for pile groups.

ii) This paper is concentrated on homogenious and isotropic soil model, we can also design for other plastic models also.

iii) Also, we have considered soil with homogenious layer. Also different layered models can also be implemented where attributes will be different with each layer.

iv) We have also considered the water table on ground surface. But it can be at certain depth also. In that case outcomes will be quite different.

v) Even than Mohr-Coulomb model, advanced soil models like Hardening Soil model, Soft Soil Creep models as well as user defined models can be used.

7. REFERENCES :

- Ambily, A.P., & Gandhi, S.R. (2007). "Behavior of stone columns based on experimental and FEM analysis." ASCE, Volume-133, Issue-4, 405–415.
- Ayadat,T., Hanna, A.M. (2005). "Encapsulated stone columns as a soil improvement technique for collapsible soil." Ground Improv, Volume-9, Issue-4, 137–147.
- Ayadat, T., Hanna, A.M. (2008). "Soil improvement by internally reinforced stone columns." Ground Improvement, Volume-161, Issue-GI2, 55–63.
- Dipty, S.I., & Girish, M.S. (2009). "Suitability of different materials for stone column construction." EJGE, Volume-14, Issue-19, 1-12.
- Donovan, M., Siaw, K.S., & Tasnim, S. (2016). "Numerical Modelling of the Consolidation Behavior of Peat Soil Improved by Sand Columns." Soil mechanics and foundation engineering, Volume- 4, Issue-16, 148-151.
- Gniel, J., & Bouazza, A. (2009)'. "Improvement of soft soils using geogrid encased stone columns." Geotextiles and Geomembranes, Volume-27, Issue-6, 167–175.
- Gniel, J., & Bouazza, A. (2010). "Construction of geogrid encased stone columns: a new proposal based on laboratory testing." Geotextile and Geomembrane, Volume-28, Issue-1, 108-118.
- Harish, C., Shashishekar, T.R., Radhika, K.N. & Manjunath, I. (2016). "Improvement of Bearing Capacity of Black Cotton Soil Using Stone Column With and Without Encasement of Geosynthetics." International Research Journal of Engineering and Technology, Volume-3, Issue-7, 56-72.
- I.S: 2720 (Part I) (1983) : "Indian standard for preparation of dry soil samples for various tests", Bureau of Indian Standards Publications, New Delhi.
- I.S: 2720 (Part III/Section 1)-1980 : "Indian standard for determination of specific gravity (fine grained soil)", Bureau of Indian Standards Publications, New Delhi.
- I.S: 2720 (Part VII)-1980 : "Indian standard for determination of water content- Dry density relationship using light compaction", Bureau of Indian Standards Publications, New Delhi.

- Kumar, N.V., Asadi, S.S., & Prasad, A.V.S. (2017). "Estimation of bearing capacity of black cotton soil using rock dust and geo textile sheet." International Journal of Mechanical Engineering and Technology, Volume-8, Issue-10, 886-895.

- Kumar, R. & Jain, P.K. (2015). "Soft ground improvement with fiber reinforced granular pile." International Journal of Advanced Engineering Research and Studies, Volume- 15, issue-4, 263-275.

- Malarvizhi. & Ilamparuthi (2007). " Comparative study on the behavior of encased stone column and normal stone column." Soils and Foundations, Volume-47, Issue-5, 873-885.

- Meshram, K., & Jain, P.K. (2015). "Strength and settlement studies of black cotton soil reinforced with granular pile." International journal of engineering sciences and research technology, Volume-4, Issue-4, 227-238.

- Murugesan, S. & Rajagopal, K. (2008). "Performance of encased stone columns and design guidelines for Construction on soft clay soils." In Proc. 4th Asian Regional Conference on Geosynthetics. June 17-20. Shanghai, China.

- Rao, L. & Madhira, M. (2010). "Evalution of optimum spacing of stone columns." Indian Geotechnical Conference. GEOtrendz. December 16-18th . IGS Mumbai Chapter. 29.

- Shahu, J.T., Madhav, M.R., Hayashi, S. (2000). "Analysis of soft ground-granular pile-granular mat system." Computer Geotech., Volume-27, Issue-1, 45-62.