REPORT :

SAFE BEARING CAPACITY ANALYSIS

TEAM ID: 210CSC

TEAM MEMBERS**:** 2210CSC1

2210CSC2

2210CSC3

2210CSC4

2210CSC5

Introduction

Before any construction over the soil, it's essential to ensure the safe bearing capacity and permissible post-construction settlement of soil. To achieve the above goal, ground improvement methods are used. As the construction time and replacement materials are limited conventional GI schemes like removal and replacement of material, stone columns, stabilisation using lime/cement and waiting period are not feasible. Based on the provided bore log data, we see that between depths of 1.5m and 16.5 m from the reference level, we have clayey soil of high plasticity of low to medium expansive that could cause a significant threat due to uneven lifting of the ground and high settlement due to surface load damaging the overlying structure. For the given soil condition and time constraints, Vacuum Consolidation Method (VCM) for ground improvement is a suitable method. The PVDs installed are capped and hence does not require any geomembrane for an air tight seal. Also the consolidation can be carried out without a surcharge load. The report covers the problem identification in the soil, installation of the PVDs, calculation check for construction settlement and the bearing capacity, cost estimation and a discussion on the overall report.

Table 1: Problem Identified in Soil profile

Soil Layer	Description	Property
CH (3.0m -4.5m)	Stiff, High-Plasticity, negative skin friction, 64% Free Swell Index (FSI)	Based on IS 1498 a 64% FSI is classified to be of Medium Potential hence puts the risk of differential settlement.
CH (4.5m -16.5m)	Very Stiff Clay of High Plasticity and medium Expansive (FSI 80%)	Classified to be of High Swell Potential. Show negative Skin Friction.

Methodology:

Ground Improvement is carried out using Vacuum Consolidation method. The main principle is to over-consolidate the soil so that on future loading, it is safe for settlement and bearing failures. This utilises the use of prefabricated vertical drains combined with vacuum pressure. Due to the application of a vacuum, a negative pore pressure is generated, increasing the effective stress of the soil without increasing the overall pressure and the total stress, thus accelerating the consolidation process. This eliminates the need for any surcharge load and increases the consolidation rate. Cap-attached Vertical drains is used to eliminate the need for geomembrane as in conventional method. The vertical drains made of jute fibre is used. The stresses due to the superstructure is first measured. The vacuum pump is then to be operated at a pressure greater than the former. It was found that almost 99% consolidation is completed in 10 days after which the structure can be built. The same methodology is applicable to both the cases of i) Roil Reinforced Wall and ii) Road Embankment.

The sand layers onto 0.3 m is excavated and the PVDs are injected into the ground using hollow steel mandrels and arranged in triangular manner to a depth of 10 m into the ground from ground level. Caps are attached to the drains and connected to horizontal drains which are then connected to vacuum pumps. The layout is then covered by the same sand excavated prior. The pump is operates for 10 days, and the pumped water is drained from a horizontal trench.

The analysis of the proposed solution is carried out in two phases, in phase I, the land is over consolidated. The surcharge pressure that the super structure apply is about 70KPa. Hence to over consolidate the pump is operated at 80KPa. This decreases the pore water pressure increasing the effective stresses from the soil. The settlement and new void ratio is then calculated. In phase II the stresses due to super structure on the clay layers is calculated and the post construction settlement

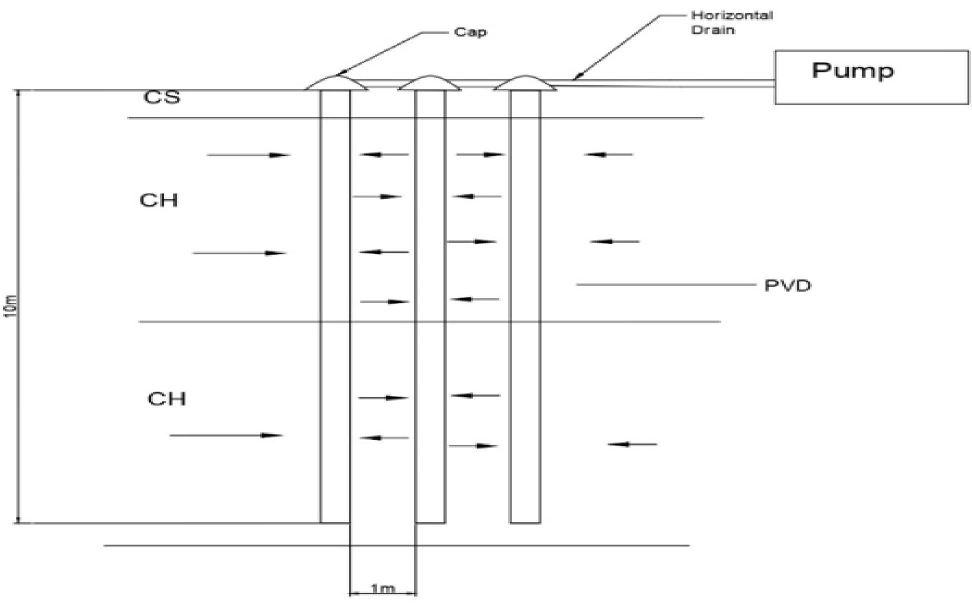

Fig. 1: Vacuum Consolidation of The Given soil Profile

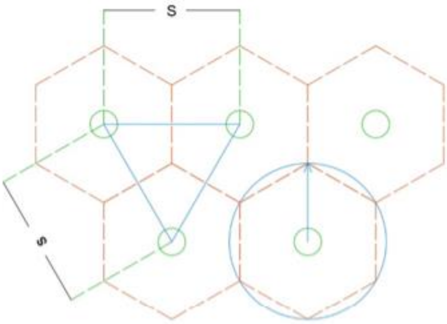

Fig.2: Triangular Arrangement of PVDs

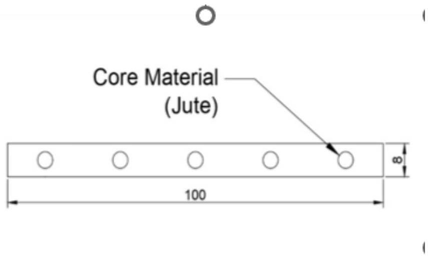

Fig 3: Cross section of PVD

Calculations

Phase I:
Over-consolidation of soil using Vacuum Consolidation Method (VCM)

The following calculation was carried out to check the degree of consolidation after a period of 10 days

1) Calculation of Influence Area Diameter (R) and Drainage Factor (n)

PVD used: Flora Drain type PVD, made of Jute fabric
Dimension: Width (b) = 10 cm or 100 mm
Thickness (t)= 8mm
Equivalent Diameter(de)= 2*(b+t)/p = 641.71 mm
Equivalent Radius(re) = (b+t)/p = 320.86 m
Spacing between PVDs (S) = 1000 mm
The PVDs are arranged in triangular manner; hence, Radius of Influence (R) = 0.564*S= 577 mm
d_n=2*R
n = d_e/d_n = 0.1811

Time Factor for Vertical Drainage (T_v) = (C_v*t)/(H^2)

2) Calculation of Time Factor and Degree of Consolidation

- For vertical Consolidation
  Coefficient of Vertical Consolidation=7.752*$PI^{-3.1021}$
  Time Factor(T_v)=C_v*t/H^2
  If T_v<0.196, T_v=0.25p$(U_v/100)^2$ — U_v: Degree of Vertical Consolidation
  If Tv>=0.196 T_v
- For Radial Consolidation
  Time factor(T_r) =C_r*t/$(2R)^2$
  Ur=1-exp(-A) — U_r: Degree of Radial Consolidation
  Where, A=8T_r/(F_n)
  F_n=n^2*ln(n)/(n^2-1) – (3n^2-1)/4n^2

  U=1-(1-U_v)*(1-U_r) — U: Degree of Net Consolidation

Table 2.1: Calculation of U_v and U_r at different depths of the clay soil

Depth(m)	C_v(sq.mm/day)	C_r	H	T_v	U_v	T_r	U_r
0.5-1.5	354812.9	354812.9	1000	1.576946	98.75553	2664.328	100
1.5-3.0	72368.49	72368.49	1500	0.321638	95.22134	543.4228	100
3.0-4.5	103983.4	103983.4	1500	0.462149	95.88944	780.8229	100
4.5-6.0	69894.06	69894.06	1500	0.31064	95.16468	524.8421	100
6.0-7.0	49149.89	49149.89	1500	0.218444	94.66246	369.0719	99.99981
7.0-9.0	44122.27	44122.27	1500	0.196099	94.53308	331.3189	99.9992
9.0-10.0	39752.89	39752.89	1500	0.17668	94.4181	298.5088	99.99717
10.0-12.0	59628.45	59628.45	1500	0.265015	94.92234	447.7565	99.99999
12.0-15.0	95074.32	95074.32	1500	0.422553	95.71123	713.9234	100
15.0-16.5	164843.2	164843.2	1500	0.732636	96.92395	1237.826	100

Depth(m)	φ(friction angle)(rad)	C(KN/m^2)
0.5-1.5	0.5149081	75
1.5-3.0	0.4560134	75
3.0-4.5	0.4692826	150
4.5-6.0	0.4547443	150
6.0-7.0	0.4419441	150
7.0-9.0	0.4380368	150
9.0-10.0	0.4342677	150
10.0-12.0	0.4489599	150
12.0-15.0	0.4659953	150
15.0-16.5	0.4862809	150

U≈99% is achieved at the end of 10 days

The vacuum suction is operated under 80KPa which is equivalent to a surcharge of the same magnitude.

After the Phase 1

Table 3: Settlement, void ratio and Saturated Density after VCM

Soil Depth(m)	S_p(m)	e_p	New Y_{sat}
1.5-4.5	0.2583	0.6332	19.88112
4.5-16.5	0.4524	0.6638	19.6953

S_p: Settlement
e_p:Void ratio after primary settlement
Y_{sat}: Saturated density

The above Ground improvement is applied for both case 1 and 2 of the problem statement

Phase 2

Case 1: Reinforced Soil Wall

The reinforced soil wall is assumed to be of 1 mm thick; and the geogrid is assumed to be of density 1gm/cc and of 1mm thick

Depth of the footing: 3 m, Width of the footing: 4.5 m

The total weight of retaining wall = 7060.704 KN
Weight on each foundation= 3530.352 KN

Table 4: Stresses due to Reinforced Soil wall

m	n	Z(m)	I	q(KPa)	Ds
0.333333333	1.5	3	0.09	784.5227	67.70431
0.222222222	1	4.5	0.05	784.5227	42.91339
0.095238095	0.4	10.5	0.02	784.5227	13.17998

Z: depth at which stress is calculate
m: breadth of footing/Z
n: width of footing/Z
I: factor depending on m and n

Table 5: Post Construction Settlement

Soil Depth(m)	Settlement(m)
1.5-4.5	0.02748195
4.5-16.5	0.03217973

Net Post Construction Settlement = 0.0595m or 59.5 mm

As the foundation is in a stiff clay, General Shear Failure is valid for the ultimate bearing capacity

$Q_u = c'N_c + q_0N_q + 0.5\gamma BN\gamma$

for effective shear angle=5°

Q_u=1688KN/sq.m

Net Ultimate Bearing Capacity (Q_{nu}) = 1635.235 KN/sq.m

With a factor of safety :4

Safe Bearing Capacity= 408.81 KN/sq.m or 41.72 t/sq.m

Case 2: Road Embankment

As stresses due to a symmetric embankment is maximum along the centre line, points along the centreline on the mid of the concerned soil layer considered.

Table 6: Settlement and Stresses at Mid section of clay layers

Z(m)	Stresses(Kpa)	Settlement(m)
3	78.358	0.026
10.5	76.86	0.038

Net Settlement = 0.064 m or 64 mm

Ultimate Bearing Capacity:

$$p = \frac{(0.25Br_3 + r_2h_2)[(1+K_0)sin\theta - (1-K_0)]\pi}{2\pi(1-U)\sin\ \theta + 2(cos - (0.5\pi - \theta)\sin\ \theta} + \frac{c_t\pi cos\theta}{\pi(1-U)sin\theta + cos\theta - (0.5\pi - \theta)sin\theta} + \frac{2c_2h_2 + K_0r_2h_2^2tan\theta_2}{B}$$

B: mean of Bottom and Top width of embankment

K_o: Earth Pressure Factor

h_2:height of the sand layer

θ: friction angle for sand layer

θ_2: friction angle for upper Clay Layer

$c_{t:}$ cohesion for Sand Layer

c_2: cohesion for Clay layer

P_u=2109.3772KPa

With factor of safety : 4

P_{uf}=215.03KPa or 53.75 t/sq.m

Cost Estimation:

Nominal cost of Jute PVD : 1200 INR/m   (Length of PVD 10m and spaced at 1m)

Rental Price for Vacuum Pump: 2000 INR per day

Nominal Price for Horizontal drains: 1500 INR/m

Excavation Cost: 1000 INR / m^3

Labor Charge: 500 INR/m^3

Estimated Cost : 35000 per sq m

Result:

After the consolidation by VCM the post construction settlement and safe bearing capacity was found to be 59.5 mm and 41.71 t/m^2 in case 1 ;and 64 mm and 53 t/sq.m in case 2 which are within the constraints of the problem statement and Estimated Cost : 35000 per sq m

Discussion:

This method of vacuum consolidation using capped PVD has the following benefits over the conventional methods that it doesn't require any geomembrane of creating an air tight seal. A 99% consolidation is achieved in 10 days as compared to the conventional VCM that may require at least half a year for the same or compared to 28 days in case of soil cementation. The use of Jute PVD makes it environmentally friendly as its decomposable.

However, a gap in the estimated time could be an under estimation due to non homogenous nature of the soil and there could be fluctuation in vacuum pressure which will require ground monitoring for ensuring an even consolidation.

Reference:

1) To obtain relation between C_v and provided plasticity index.
   Ng, K. S., Chew, Y. M., & Lazim, N. I. A. (2018). Prediction of Consolidation Characteristics from Index Properties. *E3S Web of Conferences*, *65*. https://doi.org/10.1051/e3sconf/20186506004
2) Calculation of consolidation using PVDs
   Indian Standards, B. (n.d.). *IS 15284-2 (2004): Design and construction for ground improvement - Guidelines, Part 2: Preconsolidation using vertical drains*.
3) Calculation of Bearing Capacity
   Zhu, F., Zhang, W., Dong, W., & Sun, M. (2017). A new calculation method for the bearing capacity of soft soil foundation. *Advances in Mechanical Engineering*, *9*(10). https://doi.org/10.1177/1687814017732520
4) About Vacuum Consolidation using geomembrane
   Koirala, N., Soralump, S., & Phakdimek, S. (2022). Observations from Ground Improvement Using Vacuum Consolidation Method. *Civil Engineering and Architecture*, *10*(3), 771–783. https://doi.org/10.13189/cea.2022.100303
5) Cohesion values for different types of soil:
   https://www.geotechdata.info/parameter/cohesion
6) Friction Angles https://www.geotechdata.info/parameter/angle-of-friction
7) *For specification of PVD: GOVERNMENT OF INDIA MINISTRY OF RAILWAYS PREFABRICATED VERTICAL PVC DRAINAGE SYSTEM FOR CONSTRUCTION OF EMBANKMENT ON COMPRESSIBLE SOFT SOIL PREFACE*. (2004).