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WORKING OF PREFABRICATED VERTICAL DRAIN- A CASE STUDY

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Abstract: Prefabricated vertical drains (PVD) are commonly used to decrease the drainage path within soft soils to accelerate the time of primary consolidation. Prefabricated vertical drains are displacement drains of small volume that exhibits considerably with fewer disturbances to the soil mass than the displacement sand drains. Disturbance to soil mass due to installation of PVD at three construction sites in Navi Mumbai area is evaluated in this work. This work emphasizes ground improvement mechanism for proposed embankment for double track broad gauge railway line between Belapur-Seawood-Uran areas in Navi Mumbai for chainage 19000 to 20500 along the proposed railway track. The study of the soil in this geographical region indicates that the top of the stratification contains the yellowish stiff clay. The next layer observed in the stratification contains the soft grayish marine clay which is then followed by yellowish stiff/hard clay with gravels. The subsequent layers of stratification are completely weathered rock which was then observed by moderately weathered rock. The data collected and analyzed in this study includes general soil details, index properties of compressible soil, shear strength properties, consolidation properties and pre-consolidation pressure. It has been observed that the time required for consolidation with prefabricated vertical drains is expected to be shorter as compared to the time required for the preloading alone without PVD. The closer the spacing in between prefabricated vertical drain the shorter the time required for the consolidation process. The expected consolidation settlement achieved by PVD is slightly higher than actual field consolidation settlement.

Keywords: Consolidation, PVD, Ground Improvement.

I. INTRODUCTION

Prefabricated vertical (PV) drains are commonly used to decrease the drainage path within soft soils to accelerate the time of primary consolidation. Prefabricated vertical drains are displacement drains of small volume that exhibits considerably with fewer disturbances to the soil mass than the displacement sand drains. Disturbance to soil mass due to installation of PV drains at three construction sites is evaluated in this work. Literature is reviewed in the published data regarding the performance of displacement sand drains and PV Drains. This provides the basis for an empirical approach to assess the excessive installation disturbance effects imposed by both PV drains and displacement sand drains. It has been observed that the size of the installation mandrel and the anchor are important factors in the soil disturbance. The disturbance caused by PV drains is observed to be similar to displacement sand drains in case of the drain spacing ratio based on the effective diameter of the mandrel and anchor. These estimates are designed using the mandrel and anchor combined perimeter and not the end area. With this approach, a modified drain spacing ratio i.e. effective drain spacing and effective Mandrel diameter greater than 7 to 10 is considered to be necessary to reduce the excessive disturbance effects of PV drain installation.

II. IMPORTANCE OF PREFABRICATED VERTICAL DRAIN

It is very important to stabilize soft soil before commencing any major construction work to prevent out the settlement. Many soft clay strata contain thin bands of silt or sands which result in the instability of embankments due to the horizontal spread of excess pore pressure vertical drains relives these excess pore pressures and thus avoids the occurrences of instability. The time required to reach a higher degree of consolidation under preloading improved drainage should be used in the form of prefabricated vertical drains. In order to expedite the settlement process and reduce building of pore water pressure it is necessary to restrain the flow path through the soil. This can be achieved by placing vertical drains at a regular spacing in the soil. When a heavy load, such as a road embankment or other structure is placed on the top of clay or silty clay soil, considerable settlement may occur due to squeezing out of excess pore water pressure, the soft soil consolidated. This kind of settlement often causes serious construction problems.

III. CASE STUDY

This work emphasizes ground improvement mechanism for proposed embankment for double track broad gauge railway line between Belapur-Seawood-Uran areas in Navi Mumbai for chainage 19000 to 20500. The study of the soil indicates that the top of the stratification contains the yellowish stiff clay. The next layer observed in the stratification contains the soft grayish marine clay which is then followed by yellowish stiff/hard clay with gravels. The next layers of stratification are completely weathered rock which is then observed by moderately weathered rock. Table I gives details of type of soil strata between chainage 19000 to 20500 and Table II gives loadings conditions.

TABLE I TYPE OF SOIL STRATA BETWEEN CHAINAGE 19000 TO 20500

Stratum	Description	Depth belong ground level (In meter)	Thickness (In meter)
1	Yellowish stiff clay	2.00	2.00
2	Grayish soft marine clay	6.50	4.50
3	Yellowish soft marine clay	8.50	2.00
4	Completely weathered rock	9.30	0.80
5	Moderately weathered rock	-	-

TABLE II LOADINGS CONDITIONS FOR CHAINAGE 19000 TO 20500

Sr. No.	Description	Design value
1	Initial average level	1.50 m
2	Proposed formation level	4.50 m
3	Proposed fill thickness	3.00 m
4	Unit weight of proposed fill	20 kN/m^3
5	Pressure due to fill	60 kN/m^2
6	Live load surcharge as per specification	30 kN/m^2

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The second layer of subsurface profile was identified as grayish soft marine clay. The layers undergo heavy settlements and the duration required for settlement to take place is also very high. These settlements can accelerate by prefabricated vertical drains (PVD) with surcharge. With the use of PVD water flows horizontally (radically) as well as vertically i.e. three dimensional consolidations. On application of preload these settlement can be drastically reduced. Based on study of the soil properties parameters considered for the design of band drains to determine the expected settlement and to design preload embankment and stages of preload applications are: liquid limit = 82%, γb =1.55 gm/cc and cohesion (C) = 0.15 kg/cm^2. Consolidation test shows cc = 0.86, èo =1.63, Consolidation settlement (ρc) =0.90 kg/cm^2, Coefficient of consolidation for vertical drainage (Cv) = 1.52 m^2/year and mv = 7.20 x10-2 cm^2/kg. Based on the above parameters the ground improvement technique using prefabricated vertical drain (PVD) is designed. Table III gives details of ground improvement. Based on the above data spacing of PVD is designed as 1.50 m to 2.5 m in triangular grid patterns to achieve the expected settlement with in the available time period. The site is with the triangular grid pattern of 1.5 meter spacing between two prefabricated vertical drain installation points. The expected settlement within the available time period is estimated as 292 mm. These preloads are applied in three stages and details are given in Table IV.

TABLE III DETAILS OF GROUND IMPROVEMENT

Sr. No.	**Descriptions**	**Details**
1	Proposed level of embankment	RL 4.50 m
2	Initial level of ground	RL 1.50 m
3	Difference of level	3.00 m
4	Bulk density of embankment material	20 kN/m^3
5	Load due to embankment.	60 kN/m^2
6	Live load to consider	30 kN/m^2
7	Total initial load	90 kN/m^2

IV. PRELOAD EMBANKMENT STAGES

The entire settlements to occur prior to construction the preloads are applied. These preloads are applied in three stages. These are illustrated in Table IV.

The important features of Table IV are:

a) In the initial stage there is 1.5 m up gradation of embankment height up to 3 m from bottom layer. This process is carried out for 90 days till the end of December 2012.
b) In the intermediates stage there is 1.5 m up gradation of embankment height up to 4.50 m from bottom layer. This process is carried out for 90 days till of March 2013.
c) In the final stage there is 1.5 m up gradation of embankment height up to 6 m from bottom layer. This process is carried out for 60 days till the end of May 2013.

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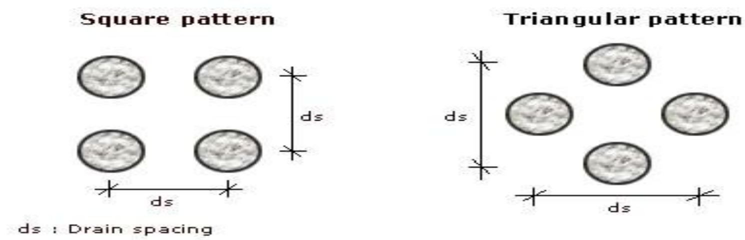

Fig.1. Patterns of prefabricated vertical drain (Holtz et al., 1991) (a) Square pattern (b) Triangular pattern

TABLE IV APPLICATIONS OF PRELOADS

Sr. No.	Working stages	Section Chainage 19000 to 20500
1	**Initial Stage**	
	Initial level	RL 1.50 m
	Final level	RL 3.00 m
	Embankment height at this stage	1.50 m
	Duration	90 days
	Working duration	Oct 2012 to Dec2012
2	**Intermediate Stage**	
	Initial level	RL 3.00 m
	Final level	RL 4.50 m
	Embankment height at this stage	1.50 m
	Duration	90 days
	Working duration	Jan 2013 to March 2013
3	**Final Stage**	
	Initial level	RL 4.50 m
	Final level	RL 6.00 m
	Embankment height at this stage	1.50 m
	Duration	60 days
	Working Duration	April 2013 to May 2013

V. INPUT DATA

Table V gives general details of soil at site, index properties of compressible soil, shear strength properties, preconsolidation pressure and consolidation properties.

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The results carried out for above parameters are illustrated in Table V. The important feature of Table V is as follows:

- The bulk density of soil is 15.50 kN/m^2.
- The liquid limit of soil is 82%.
- A compression index is 0.86.
- The plasticity index of soil is 52%.
- The angle of internal friction is 2 Degree.
- A Preconsolidation pressure is 90 kN/m^2.
- A coefficient of volume change is 0.0007 m^2/kN.
- The Preconsolidation pressure is 90 kN/m^2.
- The coefficient of vertical consolidation is 1.52 m^2/year.
- The coefficient of radial consolidation is 3.04 m^2/year.

TABLE V PARAMETER OF SOIL PROPERTIES

Soil Properties	**Unit**	**Design value**
Depth of weak soil from GL (DEPTH OF PVD)	m	6.50
Thickness of Upper In-compressible soil, Ht	m	2.00
Bulk density of upper soil, γt	kN/m^3	15.50
Thickness of weak/soft compressible soil, Hc	m	4.50
Index Properties of Compressible Soil		
Bulk Density of soil, γc	kN/m^3	15.50
Liquid limit, LL	%	82.00
Plasticity Index, PI	%	52.00
Constant for gain in shear strength, k=0.11+0.0037 PI		0.30
Shear Strength Properties		
Cohesion ,C	kN/m^2	15.00
Angle of internal friction	Degree	2.00
Consolidation Properties		
Compression index, Cc		0.86
Initial void ratio, èo		1.63
Cc / (1+e0)		0.33
Recompression index, cr’		0.07

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Coefficient of secondary consolidation		
Preconsolidation pressure	kN/m^2	90.00
Coefficient of volume change, mv	m^2/kN	0.00072
Coeffient of vertical consolidation, cv	$m^2/year$	1.52
	cm^2/s	0.00048
Cr/cv ratio		2.00
Coefficient of radial consolidation, cr	$m^2/year$	3.04
	cm^2/s	0.00096

VI. PREFABRICATED VERTICAL DRAIN/BAND DRAIN DETAILS

The basic details of designed Prefabricated vertical drain are illustrated in Table VI. The width of the band drain (Bb) carried out for site work is 100 mm. the thickness of band drain (Tb) is kept as 4 mm. the installation of prefabricated vertical drain is carried out for 3 m to 14 m.

TABLE VI BASIC DETAILS OF VERTICAL DRAIN

Sr. no.	Proposed PVD	Unit	Design value
1	Width of band drain, Bb	mm	100.00
2	Thickness of band drain, Tb	mm	4.00

VII. LOAD DETAILS

The load details carried out for the particular embankment work are as shown in Table VII.

TABLE VII LOAD DETAILS FOR EMBANKMENT WORK

Sr .No.	Load Details	Unit	Design value
1	Maximum hgt. of embankment, He	m	3.00
2	Density of embankment material, γe	kN/m^3	20.00
3	Surcharge load if any,	kN/m^2	30.00

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VIII. Settlement Estimates

For the cohesive fine soils, the consolidation settlements are of major concern as this is a long term phenomenon. The consolidation settlement depend on the type of soil i.e. normally consolidated; sub consolidated; over consolidated. For the over consolidated soil the most appropriate method to determine the settlement is based on the coefficient of volume change i.e. mv.

The consolidation settlement are calculated as-

$$\delta = mv * \Delta P * Hc * 1000 \quad (1)$$

Where, δ= Settlement in mm

Hc= Thickness of Compressible layers in meters

mv = Coefficient of Volume Change of Soil for Layer under Construction

ΔP = Applied Pressure Intensity

An estimation of consolidation settlement is given in Table VIII.

The main feature of Table VIII is as follows:

The height of embankment (He) is kept as 3.00 m. The surcharge load carried out for consolidation settlement is 30 kN/m^2. The applied pressure intensity (ΔP) for the consolidation settlement is 90 kN/m^2. The thickness of compressible soil (Hc) is 4.50 m.

TABLE VIII CONSOLIDATION SETTLEMENT ESTIMATION

Sr. No.	**Description**	**Unit**	**Design value**
1	Height of embankment. He	m	3.00
2	Density of embankment material, γe	kN/m^3	20.00
3	Surcharge load	kN/m^2	30.00
4	Applied pressure intensity, ΔP	kN/m^2	90.00
5	Thickness of compressible soil, Hc	m	4.50
6	Coefficient of volume change, mv	m^2/kN	0.00072
7	δ= mv*ΔP*Hc*1000	mm	292.00
8	Total primary settlement	mm	292.00

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As per the above analysis the total minimum primary settlement achieved by the prefabricated vertical drain should be 292 mm.

IX. TIME ESTIMATION-USING PREFABRICATED VERTICAL DRAIN

As per the theory of three dimensional consolidations, U =1- (1-Uz) (1-Ur) (2)

Where, U=Degree of consolidation settlement
Uz = degree of consolidation in vertical direction
Ur = Degree of Radial Consolidation

However, the degree of consolidation in vertical direction is very less as compared to the degree of consolidation in radial direction 'Ur'. Hence, to determine optimum spacing it can be neglected. Spacing of PVD shall be determined considering the radial direction only.

By using Barron theory, time required for consolidation using band drain is calculates as below and the final result of trial analysis is illustrated in Table IX.

$$t = D^2 / 8\, C_r\, [1/1- (d_{bd} / d)^2 * \ln (D / d_{bd}) - (3/4) + (1/4 * (d_{bd} / d^2)] * \ln (1/ (1-U) \quad (3)$$

Where, t = Time required for Consolidation, in years
d = Effective Diameter of area covered by each Band Drain in meter.
dbd = Effective Diameter of Band Drain in meters
= 2 (Bb + Tb)/π
= 0.066 m

TABLE IX TIME ESTIMATION FOR CONSOLIDATION SETTLEMENT

Sr. No.	Description	Trial result
1	Grid pattern	Triangle
2	Consider spacing of PVD.	1.50 m
3	Hence ,D	1.58 m
4	Required consolidation, U%	90.00
5	Say, a= (D/dbd)	23.79
6	Hence , ln (D/dbd)= ln (a)	3.17
7	Dbd/D =1/a	0.042
8	D^2/8cr	0.102
9	1/(1-(dbd/D^2) =(1/(1-(1/a^2)	1.002
10	In (1/(1-U)	2.303
11	Time ,t	0.570 years
12	Time, t	6.84 months
13	Time, t	208 days
14	Depth of pad from EGL	6.50 meter

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X. PRELOAD DESIGN CHECK

To help the expected settlement to occur prior to the actual construction, the preload shall be placed after installation of band drain.

Preload shall be applied in stages. After each stage of loading, sufficient waiting period or pause period shall be allowed to consolidate the soil under the load. This load will be associated with the gain in shear strength of the soil due to applied load and the SBC of soil will increase.

The excess load may cause the plastic flow of soil or detrimental effects to adjoining structure. Hence, the design of preload and it's checking very important.

The main features of preload design are as follows:

- The factor of safety is assumes as 1.25.
- The surcharge load is 30 kN/m^2.
- The density of embankment material is 20 kN/m^3.

The important requirements by the preload design check are as follows:

a) There should be well design consolidation settlement achieve in each stages throughout the project work.
b) The presume time capacity to complete the consolidation settlement should be achieve.
c) The degree of radial consolidation for each stage must be well and accurate in percentage which is most important factor to achieve the pre assume target work.
d) As per the above analysis the total minimum primary settlement achieved by the prefabricated vertical drain should be more than or equal to 292 mm.

The details of preload design check are illustrated in Table X.

TABLE X PRELOAD DESIGN CHECK

Stage of loading	**Unit**	**1.00**	**2.00**	**3.00**
Time	days	90.00	90.00	60.00
Initial height	m	-	1.50	3.00
Fill height at end of stage	m	1.50	3.00	4.50
Additional pressure	kN/m^2	30.00	30.00	10.00
Spacing provide	m	1.50	1.50	1.50
Grid pattern		Triangle	Triangle	Triangle
Dia of each unit	m	1.58	1.58	1.58
Effective dia of band drain	m	0.066	0.066	0.666
D/dbd		23.79	23.79	23.79
D^2/8Cr		0.10	0.10	0.10
Ln (1/1-U)		1.00	1.00	0.66
Degree Of Radial Consolidation Ur	%	63.09	63.09	43.62
Initial Cohesion, Ci	kN/m^2	15.00	20.72	26.45
Pressure IncrementΔps	kN/m^2	30.00	30.00	10.00

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Increase In Cohesion $\Delta c=k*\Delta ps*U$	kN/m^2	5.72	5.72	1.47
Final Cohesion, CF=CI+Δc	kN/m^2	20.72	20.72	27.92
Let, Factor Of Safety		1.25	1.25	1.25
SBC After Consolidation	kN/m^2	94.50	120.60	127.30
Total Ht. Of Fill	m	4.73	6.03	6.36
Final Ht. For Next Stage	m	3.00	4.50	-
Density Of Embankment Material,γe	kN/m^3	20.00	20.00	20.00
Surcharge Load	kN/m^2	30.00	30.00	30.00
Applied Pressure Intensity ΔP	kN/m^2	60.00	60.00	40.00
Thickness Of Compressible Soil,Hc	kN/m^2	4.50	4.50	4.50
COEFFICIENT OF VOLUME CHANGE, mv	m^2/kN	0.00072	0.00072	0.00072
$\delta= mv*\Delta P*Hc*1000$	mm	194.00	194.00	130.00
Settlement by Ur=((δ*Ur)/100)	mm	122.00	122.00	57.00
Total settlement due to preload ==((δ/Ur)*100)	mm	307.00	307.00	298.00
Total expected settlement	mm	292.00	292.00	292.00

Hence, from the Table X we get,

The total minimum primary settlement achieved by the prefabricated vertical drain is 307.00 mm which is more than the pre assume consolidation settlement of 292 mm.

For Stage One and Stage Two,
Total expected settlement 292 mm < 307.00 mm hence ok.

For The Stage Third
Total expected settlement 292 mm < 307.00 mm hence ok.

XI. CONCLUSION

The time required for consolidation with prefabricated vertical drains is expected to be shorter as compared to the time required for the preloading alone without PVD. The expected consolidation settlement achieved by PVD from the calculation is slightly higher than actual field consolidation settlement. The closer the spacing in between prefabricated vertical drains, the shorter the time required for the consolidation process. The advantages of square pattern are that it is more convenient to lie out and manage on site. However, triangular pattern is the most popular one because it provides a more uniform consolidation between drains than square pattern. A comparison between embankments stabilized with a PVD combined with a surcharge, and a surcharge alone, were analysed and discussed. Consolidation time with a PVD applied was substantially reduced and lateral displacement curtailed, and if sufficient vacuum pressure by PVD is sustained, the thickness of the surcharge fill required may be reduced by several meters. However, the differences between vacuum and surcharge preloading have not been investigated in depth. But, in the absence of comprehensive and quantitative analysis i.e. 2D analysis and 3D analysis, the study of suitable method i.e. PVD to stimulate vacuum preloading become imperative both experimentally and numerically in major project work.

XII. FUTURE SCOPE

Future work should focus more on the following aspects:

1) More laboratory tests should be carried out to study the behavior of soft clay under different combinations of vacuum and surcharge pressures and using PVD of different properties and soils of varying compressibility and undrained strength.
2) In order to detect the failure of embankment constructed on soft clay, it is recommended to carry out a parametric study on the assumed plane strain model.
3) Further research with selected 'instrumented PVD' in the field is desirable as it may provide further insight to the vacuum pressure distribution development with depth.
4) The Detail stress path testing of site foundation soil in order to obtain the most accurate soil properties specifically regarding with the preconsolidation pressure of soil.
5) Various parameters such as the construction rate, embankment slope, and drain spacing etc. should be taken into account, and finally, a numerical scheme may be developed to estimate the maximum fill height that will be of paramount importance to the designer.
6) It is important to evaluate the coefficient of saturated permeability of the soil as accurate as possible
7) For, each soil type, moisture characteristics curve should be developed and use in the proposed finite element model.

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