The Design of the Vertical Sand Drain

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ABSTRACT

A vertical sand drain is designed to allow fluids to drain from clay or silty soil by drilling a hole and filling it with sand or gravel. Sand drains are required for building in places where drainage is limited due to extremely fine soils, such as clay or silt. Therefore, when assessing design assumptions and construction costs to determine whether sand drain stabilization is feasible for a particular project, the impact of the sand drain installation method on the in situ characteristics of the subsoil being treated is crucial. It is the purpose of this paper to review the design of sand drain installations for use in foundation stabilization with or without using sand drain piles. The results show that untreated soil consolidates slowly in two cases (H = 6m and 12m), especially for deeper layers, requiring nearly 1000 days to reach approximately 60% consolidation while sand drain treatment dramatically reduces consolidation time; in the treated case with SD = 1.5m achieves near-complete consolidation within approximately 100 days, and another case reaches similar consolidation levels within approximately 200 days with SD = 2m. The findings suggest that reducing sand drain spacing and employing sand drain treatment effectively reduce consolidation time, which is essential for construction projects involving soft soil layers.

Keywords: *vertical sand drain, soft soil, construction, stabilization, consolidation*

INTRODUCTION

A strategy or approach used to improve land that is in poor condition or in a disturbed state is called soil improvement. To improve the properties of the current soil, it is re-engineered using a variety of geotechnical techniques. In order to satisfy the specifications of the kind of construction that will be built on that specific plot of land, soil improvement is typically carried out.

In addition to improving weak soils, ground improvement techniques also improve inappropriate and contaminated soils. One advantage of soil improvement is that it takes less time because it is relatively quick to plan and implement. Additionally, when the procedures are used for ground improvement, very little waste is produced. Thus, it involves no disposal expenses; the substructure is simple to design and build, and ground improvement works well on a variety of soil types.

Figure 1. Soil Improvement in the Construction Industry [1]

There are numerous options for soil improvement. However, each technique has unique advantages and disadvantages in terms of time, performance, and cost. Soil improvement procedures include pre-compaction, sand drains, wick drains, stone columns, deep mixing, and grouting. The primary purpose of most soil improvement measures for decreasing liquefaction dangers is to prevent significant increases in pore water pressure during earthquake shaking. This can be accomplished by densifying the soil and increasing its drainage capacity. This study will focus on vertical sand drain systems for pre-loading and hence pre-consolidating soils before building begins. The goal is to ensure that all settlement takes place before or during construction, not after.

2. METHOD

2.1. An overview about the vertical sand drain pile

Liquefaction concerns can be avoided by improving soil drainage. If porewater within the soil can freely drain, surplus pore water pressure will be decreased. Vertical drains are commonly used to consolidate soft clay, silt, and compressible materials. They consist of a succession of vertical sand drains or piles.

Medium to coarse sand is typically used. The drains have a diameter of at least 30cm and are arranged in a square grid pattern at 2 to 3 meter intervals. Economy necessitates a thorough examination of the influence of sand drain spacing on consolidation rate.

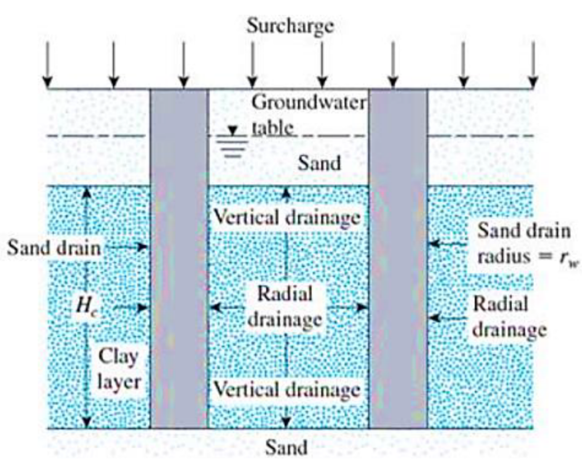

Figure 2. Schematic figure illustrates the sand drains [2]

- Vertical drain depth should be equal to the thickness of the compressible layer.

- A horizontal blanket of free draining sand should be laid on top of the stratum, which can be as thick as a meter.

- An embankment is gradually built on top of the sand blanket to provide a soil surcharge.

2.2. Design the vertical sand drain pile

Design the vertical sand drain pile [3]:

Step 1. Using a specified time, t and coefficient of consolidation, C_v, and the drainage path without sand drains, calculate the time factors, T_v; $T_v = \frac{C_v t}{H^2}$

Step 2. Use the theoretical time factor, T_v, to find the corresponding U_v. This gives the degree of consolidation that can be obtained without the use of radial drains.

Step 3. If U_v is less than the required degree of consolidation, then calculate the required U_h; $U_h = 1 - \frac{1-U_h}{1-U_v}$.

Step 4. Choose a specific well-drain diameter, d_w and solve for the effective radial drainage, R, where, R = $n_r w$; n = constant and r_w = radius of well.

2.3. Install the vertical sand drain piles

Sand drains are built by drilling holes through the clay layer with rotary drills, continuous flight augers, or by pushing hollow mandrels into the soil. The holes are subsequently filled with sand. When a surcharge is applied to the ground surface, the pressure of pore water in the clay increases, which is then dissipated via draining in the horizontal as well as vertical directions. As a result, the settlement process is hastened (Fig.2).

Sand drains can be used to form sand piles. They help to reinforce the soft ground in which they are placed. Even hif sand drains substitute only 1 to 2% of the soil volume, the total increase in bearing capacity could be more than 10% [4].

However, they do have certain disadvantages [5, 6]:

• Installing sand drains by driving hollow mandrels disturbs the soil around each drain. This may decrease the amount of water into the drain.

• During the filling, sand bulking may occur, resulting in voids.

• The huge dimension of sand drains may cause construction and/or budgetary issues.

2.4. Patterns of vertical sand drain piles

There are several common patterns of vertical sand drain columns used in ground improvement techniques, each with different efficiency levels in terms of soil consolidation and drainage performance. Here are the most widely used patterns:

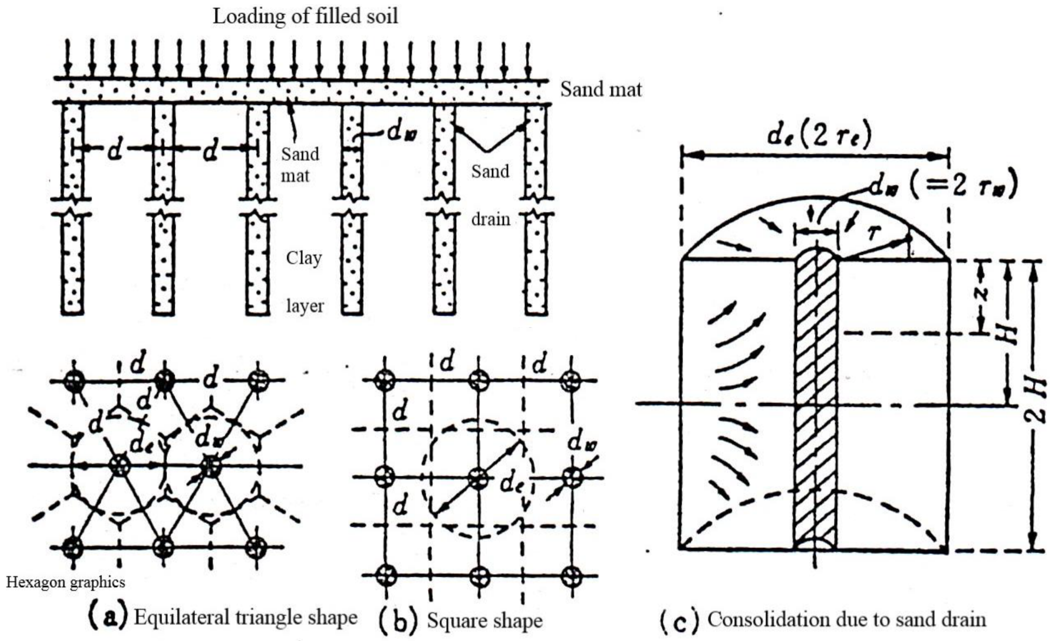

Figure 3. Installation of sand drain piles [7]

2.4.1. Rectangular Pattern

Similar to the square pattern but with different spacing in one direction (longer in one axis).

Spacing: The horizontal distance x differs from the vertical distance y.

Advantages: Suitable for sites where one direction of drainage needs to be more effective.

Disadvantages: May lead to uneven consolidation rates if spacing is too irregular.

2.4.2. Square Pattern

Sand drains are arranged in a grid-like square pattern.

Spacing: Equal distance d between adjacent drains in both horizontal and vertical directions.

Advantages:

Simple and easy to implement.

Works well for uniform soil conditions.

Disadvantages: Less efficient than triangular patterns in terms of reducing drainage distance

2.4.3. Consolidation due to sand drains

The diagram on the right shows the radial consolidation effect around a sand drain.

The drainage path is influenced by the cylindrical influence zone around each sand drain.

The effective drainage diameter ($d_c = 2r_e$) represents the area of influence for each sand drain.

Water within the clay layer is forced to move towards the sand drains due to the applied load, reducing pore water pressure and increasing consolidation rate.

The consolidation process is depicted with the movement of water towards the sand drain, leading to a decrease in settlement over time.

3. CALCULATION CASE OF THE VERTICAL SAND DRAIN PILES

Suppose the thickness of two soft layers are 6 and 12m, and each layer is divided into untreated area and sand pile treated area. 40-cm-diameter sand piles are set in the treated area with pitches of 1.5m and 2.0m and the piles are arranged in the equilateral triangle shape. Try to find and draw the consolidation curves of the above conditions. The coefficient of consolidation is:

$c_v = c_{vh} = 4.5\text{x}10^{-2}\ \text{cm}^2/\text{min} = 6.48\text{x}10^{-3}\ \text{m}^2/\text{day}$

(1) Calculation without sand drain piles:

Based on Table of variation of T_v with U, it can be performed at the below table 1:

Table 1: Variation of T_v with U

U(%)	T_v	U(%)	T_v
0	0	50	0.197
5	0.00196	55	0.239
10	0.00785	60	0.286
15	0.0177	65	0.304
20	0.0314	70	0.403
25	0.0491	75	0.477
30	0.0707	80	0.567
35	0.0962	85	0.684
40	0.126	90	0.848
45	0.159	95	1.129

Time of consolidation can be calculated using this formula:

$$t = \frac{H_{dr}^2 . T_v}{C_v}$$

Where $C_v = C_{vh} = 4.5\text{x}10^{-2}\ \text{cm}^2/\text{min} = 6.48\text{x}10^{-3}\ \text{m}^2/\text{day}$

Time of consolidation can be computed in Table 2.

Table 2: Time of consolidation of untreated soil

U(%)	T_v	Time (day)	
		H = 6m	H = 12m
0	0	0	0
5	0.00196	11	44
10	0.00785	44	174
15	0.0177	98	393
20	0.0314	174	698
25	0.0491	273	1091
30	0.0707	393	1571
35	0.0962	534	2138
40	0.126	700	2800
45	0.159	883	3533
50	0.197	1094	4378
55	0.239	1328	5311
60	0.286	1589	6356
65	0.304	1689	6756
70	0.403	2239	8956
75	0.477	2650	10600
80	0.567	3150	12600
85	0.684	3800	15200
90	0.848	4711	18844
95	1.129	6272	25089

(2) Calculation with sand drain piles:

Diameter of sand piles (d_w) = 40cm

Pitches = 1.5m and 2.0m

Patterns of piles = the equilateral triangle shape

We have installation of sand drain piles are the equilateral triangle arrangement, the diameter of effective circle (the area controlled by one sand pile) is: $d_e = 1.05d$

Where: d = the pitch of sand piles.

We need to find the relative between U_h and T_h of ground after installation of sand drain piles.

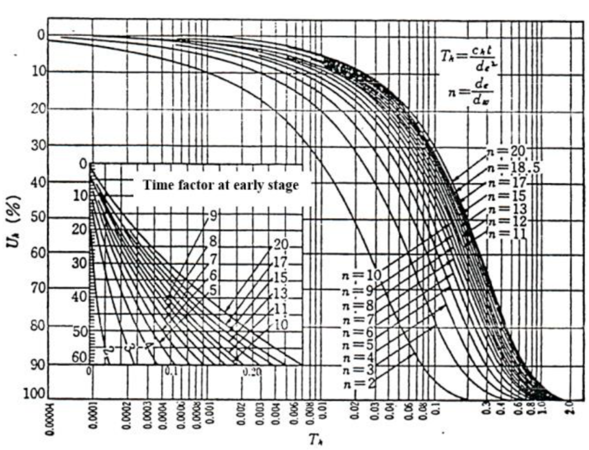

Figure 4. Relationship of U_h and T_h [7]

✓ The diameter of effective circle:

For pitches of 1.5m:

$$d_e = 1.05 \text{ x } 1.5 = 1.575 \text{ (m)}$$

For pitches of 2.0m:

$$d_e = 1.05 \text{ x } 2.0 = 2.1 \text{ (m)}$$

The coefficient of consolidation:

$C_v = C_{vh} = 4.5\text{x}10^{-2}\ cm^2/min = 6.48\text{x}10^{-3}\ m^2/day$

✓ The values of n in the Fig. 4, $d_w = 0.4$m:

For pitches of 1.5m, $d_e = 1.575$m:

$$n = \frac{d_e}{d_w} = \frac{1.575}{0.4} = 3.9375 \approx 4.0$$

For pitches of 2.0m, $d_e = 2.1$m:

$$n = \frac{d_e}{d_w} = \frac{2.1}{0.4} = 5.25 \approx 5.3$$

Table 3: Calculation of treated soil using sand drain piles

Using: $t = \frac{d_e^2.T_h}{C_{vh}}$

Where: $d_e = 1.575$m and $d_e = 2.1$m

U (%)	Coefficient of consolidation (T_h)		Time (day)	
	SD = 1.575m (n = 4.0)	SD = 2.1m (n = 5.3)	SD = 1.575m (n = 4.0)	SD = 2.1m (n = 5.3)
0	0	0	0	0
5	0.0023	0.0021	1	1
10	0.005	0.0072	2	5
15	0.011	0.017	4	12
20	0.018	0.023	7	16
25	0.022	0.035	8	24
30	0.028	0.042	11	29
35	0.037	0.053	14	36
40	0.044	0.061	17	42
45	0.056	0.074	21	50
50	0.065	0.085	25	58
55	0.078	0.097	30	66
60	0.085	0.129	33	88
65	0.092	0.148	35	101
70	0.119	0.167	46	114
75	0.142	0.178	54	121
80	0.175	0.22	67	150
85	0.19	0.26	73	177
90	0.24	0.32	92	218
95	0.33	0.42	126	286

From results of calculations, it can be shown below (Fig. 5):

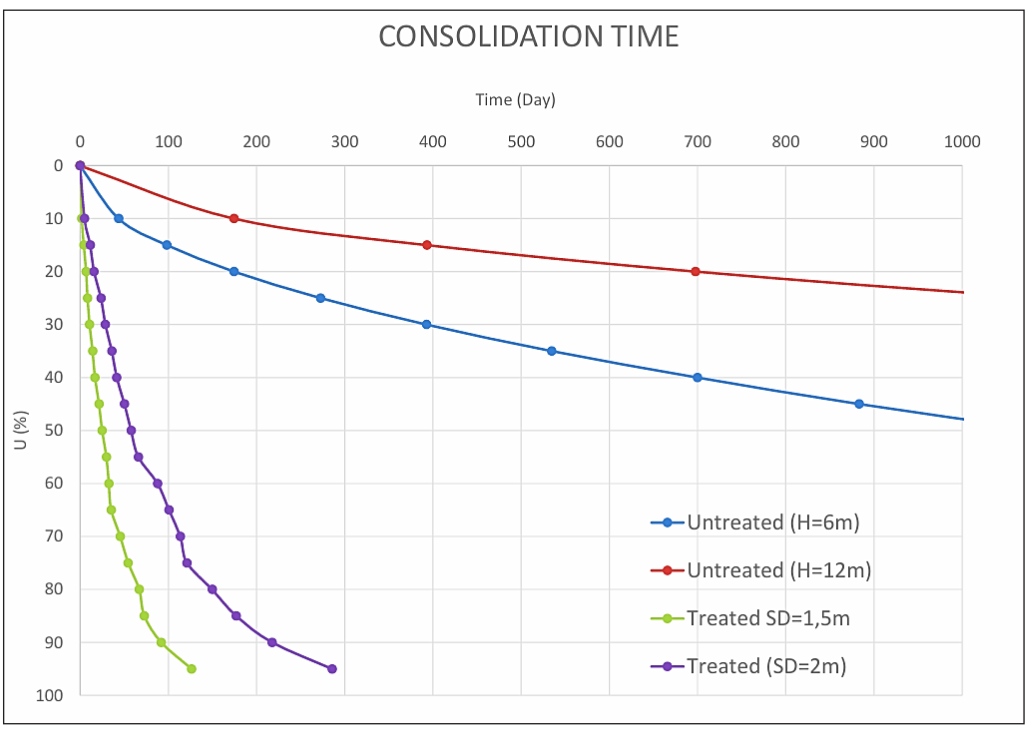

Figure 5. Consolidation time of untreated soil and treated soil using sand drain piles

Fig. 5 shows consolidation Time graph presents the consolidation percentage U over time for different soil treatment conditions.

In the untreated soils that means without using sand drain piles, the blue curve (untreated, H = 6m) consolidates faster than the red curve (untreated, H = 12m). This indicates that a thicker clay layer takes longer to consolidate, as expected due to the longer drainage path and increased water content in deeper soils.

For soils with using sand drain piles, it can be seen significantly faster consolidation compared to the untreated cases. Besides the purple curve (SD = 2m) consolidates even faster than the green curve (SD = 1.5m), indicating that larger sand drain spacing (or diameter) improves drainage and reduces consolidation time.

Generally, untreated soils take much longer to reach the same level of consolidation compared to treated soils. Treated soils with sand drains consolidate within a few hundred days, while untreated soils take several hundred or even close to 1000 days to reach high consolidation levels. Sand drains accelerate consolidation by shortening the drainage path and improving water dissipation.

4. CONCLUSIONS

From above results show that:

Untreated soil (H = 6m) performs slightly better consolidation rates compared with untreated soil (H = 12m) but remains inefficient compared to treated soils.

The treated soils with SD = 1.5m achieve near-complete consolidation within approximately 100 days, whereas the SD = 2m soils reach similar consolidation levels within approximately 200 days.

Therefore, using sand drains significantly enhances soil stabilization, making it a practical solution for reducing construction time in projects involving soft clay. In addition to increasing the spacing or diameter of sand drains (SD) further speeds up the consolidation process. When dealing with thicker clay layers, it becomes even more critical to apply ground improvement techniques to avoid long-term settlement issues.

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