

## Geotechnical Properties of Soft Improved Ground from in-situ Time-Settlement Plots

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### Abstract:

Reduce the amount of time it takes for primary consolidation by improving the ground using PVDs or sand drains. Consolidation often happens over time when surcharge load is built up. The degree of consolidation at the end of construction period for sand drain treated ground is used to estimate the coefficient of consolidation in this research. A small number of test cases are used to estimate the coefficient of consolidation using the suggested approach. This means that the time-settlement plots may be used to determine the in situ coefficient of consolidation at early dates.

**Keywords:** coefficient of consolidation, sand drains, Asaoka plots

### Introduction

Soft clays undergo three distinct phases of settlement: immediate, consolidation, and creep, sometimes known as secondary settlements. The consolidation process is responsible for the majority of the settling in soft clay. The initial consolidation settling is time-consuming because to the very poor permeability. There has to be action to enhance the stability and serviceability of structures built on soft soils.

To get past these obstacles, you need to use ground improvement methods. When it comes down to it, ground improvement methods are all about making the soil stronger in shear and less compressible in compressibility. To hasten the dissipation of excessive pore pressures, the prefabricated vertical drain approach is a viable option. The time it takes for primary settlement to occur may be drastically reduced by adopting a ground improvement technology that involves prefabricated vertical drains (PVD) in conjunction with surcharge or preloading. Sand drains or PVDs drastically reduce the drainage route.

The article suggests a technique that uses in situ time-settlement plots to estimate the coefficient of consolidation for radial flow. For radial flow and time-dependent loading in the equal strain situation, Schiffman (1958) provided the solution for the degree of consolidation,  $U_r$ . After the building phase ends, in the no smear (s becomes unity) scenario, the degree of consolidation,  $U_{rt0}$ , is

$$U_{r(t_0)} = 1 - \frac{F(n)}{8T_{R0}} \left[ 1 - e^{-\frac{8T_{R0}}{F(n)}} \right] \quad (1)$$

where  $T_{R0} = \frac{c_{vr} \cdot t_0}{4d_e^2}$  - the time factor at the end of construction

$$F(n, s) = F_1(n, s) + \theta F_2(n, s) \quad (2)$$

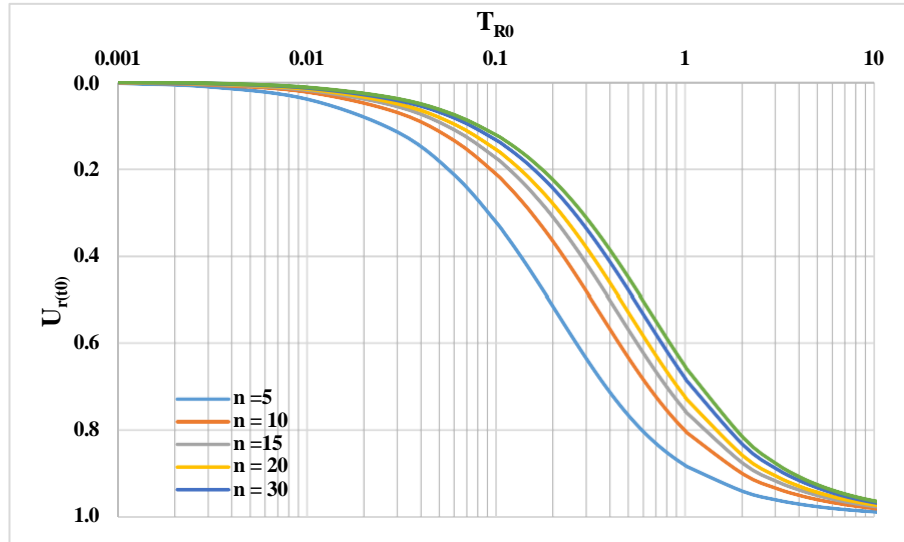
$$F_1(n, s) = \frac{n^2}{n^2 - s^2} \ln\left(\frac{n}{s}\right) + \frac{s^2 - 3n^2}{4n^2} \quad (3)$$

$$F_2(n, s) = \frac{n^2}{n^2 - s^2} \ln(s) \quad (4)$$

For drains placed in a square pattern, the ratio of the unit cell diameter,  $d_e$ , to the drain diameter,  $d_w$ , is  $1.128S$ ; for drains built in a triangle pattern, the ratio is  $1.05S$ .  $S$  - distance between each drain. the radial flow coefficient of consolidation,  $s$ , which is the ratio of the smear zone radius to the drain radius,

and  $c_{vr}$ , the smear factor.

Figure 1 shows a plot of the degree of consolidation,  $U_r(t_0)$ , with respect to the time factor,  $T_{R0}$ , at the conclusion of the building period for various values of 'n', where 'n' is the ratio of the unit cell,  $d_e$ , to the drain,  $d_w$ .



**Fig. 1** Degree of consolidation,  $U_{r(t_0)}$  versus Time-factor,  $T_{R0}$  for different values of 'n'.

As shown in Figure 1, the degree of consolidation,  $U_{r(t_0)}$ , grows as the time factor,  $T_{R0}$ , approaches the completion of construction. On the other hand, when the spacing of the PVDs or sand drains rises, it decreases.

Implementation of the suggested

approach

The Asaoka technique is used to estimate the final/ultimate settlement,  $S_{ult}$ , from a given time-settlement plot [2]. Using the in situ time - settlement data, we record the settlement,  $S_{t_0}$ , at the end of construction time ( $t_0$ ). How much of a bond forms,  $U_{r(t_0)}$ , is

$$U_{r(t_0)} = \frac{S_{t_0}}{S_{ult}} \quad (5)$$

The time factor,  $T_{R0}$ , corresponding to the end of construction, is obtained from Fig. 1 from the estimated  $U_{r(t_0)}$  and the known value of 'n'. The coefficient of consolidation with radial flow,  $c_{vr}$  is then estimated from the known values of  $t_0$ ,  $T_{R0}$  and  $d_e$ , as

$$c_{vr} = \frac{T_{R0} \times d_e^2}{t_0} \quad (6)$$

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This method is applied to few case studies reported in literature.

The southern Iraqi mud flats (1.1) (Al Alusi et al., 1977):

In southern Iraq, on the Arabian Gulf, you may find mud flats that extend from the deltas of the Tigris and Euphrates rivers. About 10 metres of typically consolidated clay to silty clay with sand and/or silt appears to under the site. The clay is delicate and sensitive. Soil has a plasticity index ranging from 20 to 28, and its unit weight is  $1.8 \text{ g/cm}^3$ . The compression index is 0.346 and the initial void ratio is 0.81. A, B, and C tanks were constructed, each with a

diameter of 76.2 m. Underneath Tanks A, B, and C, sand drains with a diameter of 0.3 m were laid down in a triangle arrangement with 2.0 m, 2.25 m, and 2.5 m spacing, respectively. The unit cell's diameter to the well's diameter ratios are 7.0, 7.875 and 8.75, respectively, using the formula  $n = d_e/d_w$ . Figures 2, 3, and 4 provide the observed time vs settlement plots for Tanks-A, B, and C, correspondingly.

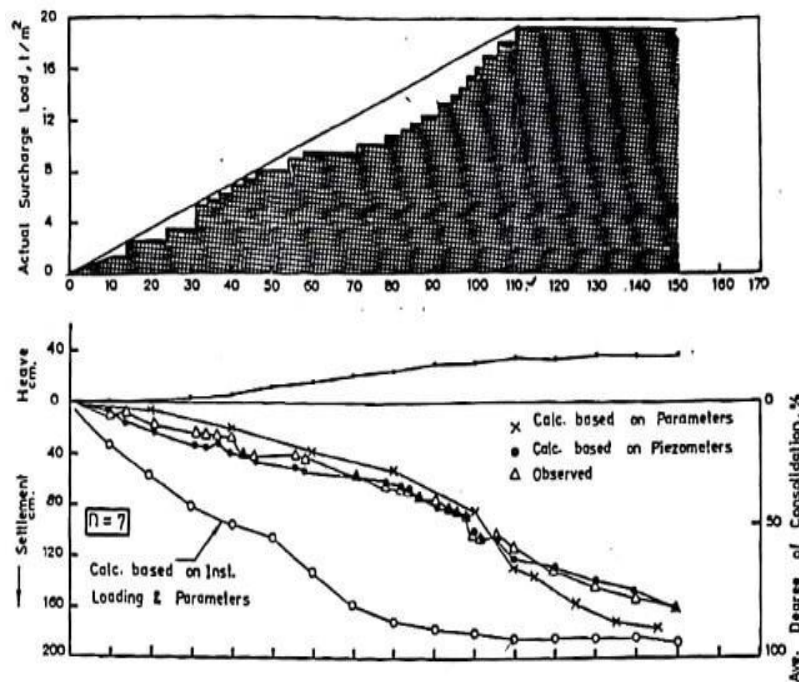


Fig. 2 Observed time vs settlement of Tank-A

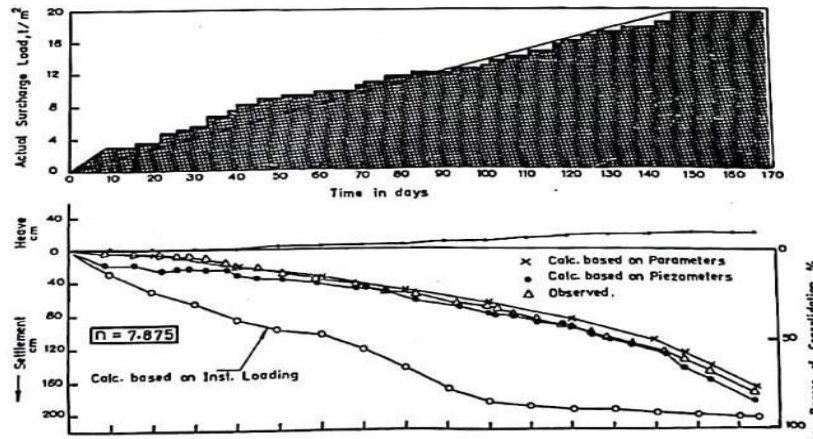


Fig. 3 Observed time vs settlement at Tank-B

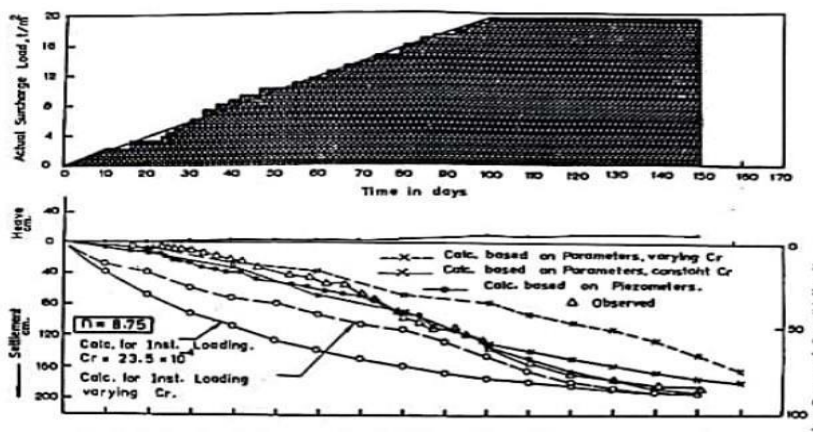


Fig. 4 Observed time vs settlements at Tank-C

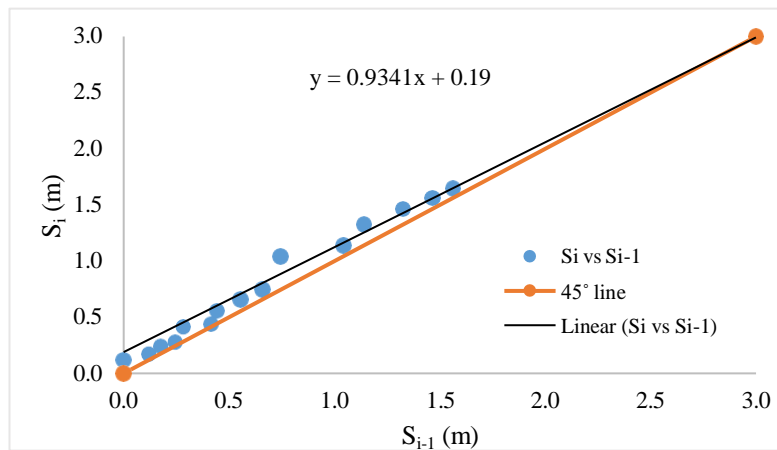
In Figures 5, 6, and 7, we can see the Asaoka plots for Tanks A, B, and C, respectively, with a 10-day time step. Tanks A, B, and C all had 2.7 m, 3.4 m, and 2.9 m ultimate settlements,  $S_{ult}$ , respectively, with line fitting slopes of

0.934, 0.956, and 0.93. At the conclusion of construction, the settlements  $S_0$  and the times  $t_0$  are 1.14 m and 110 days, 1.18 m and 150 days, and 1.2 m and 100 days, respectively. Levels of solidification at

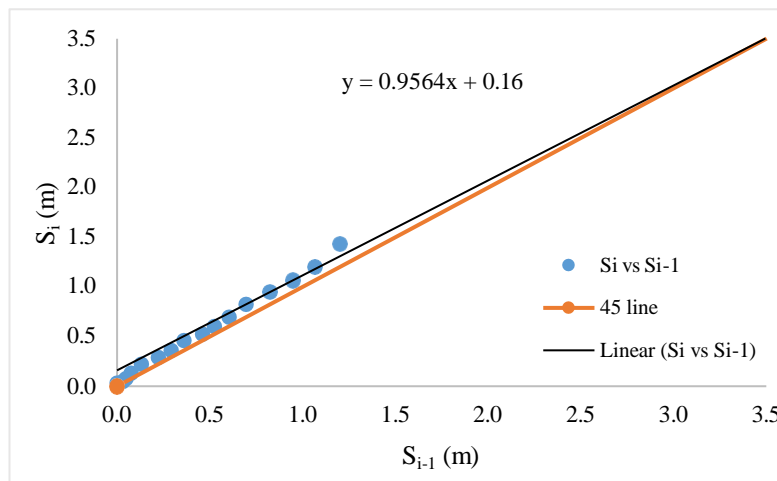
final assembly,  $U_r(b_0)$

The  $S_{blt}$  and the  $S_{bdZ}$  are 0.42, 0.35, and 0.41, respectively.

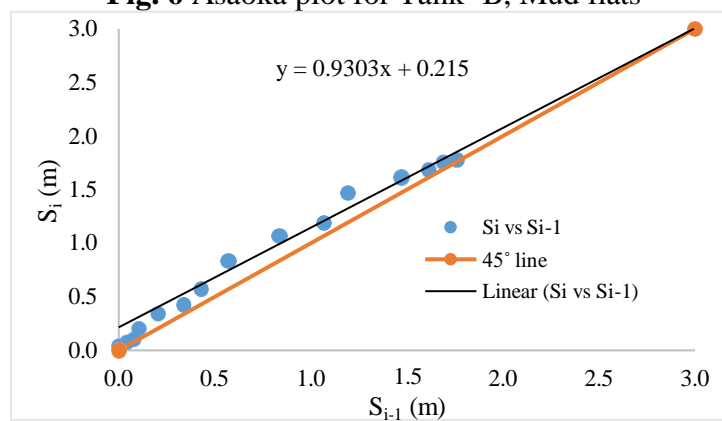
According to Figure 1, the appropriate time factors,  $TR_0$ , are 0.18, 0.16, and 0.2. According to Equation 6, the radial flow coefficients of consolidation,  $c_r$ , are  $c_{vr} = 2.63$ , 2.17, and 5.05  $m^2/year$ .



**Fig. 5** Asaoka plot for Tank-A, Mud flats



**Fig. 6** Asaoka plot for Tank- B, Mud flats



**Fig. 7** Asaoka plot at Tank-C, Mud flats

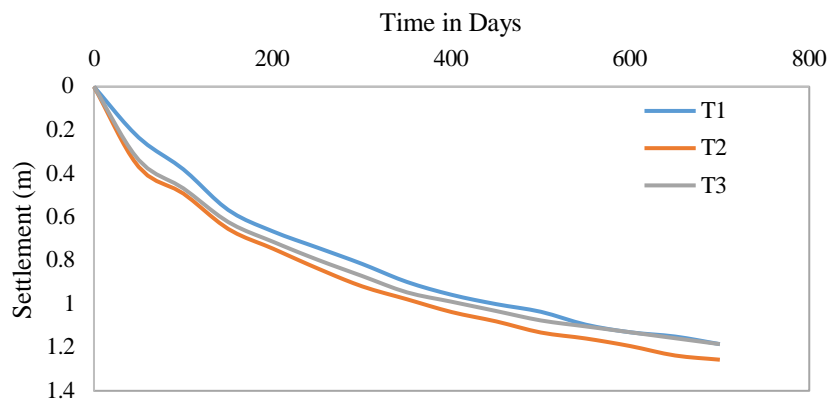
### 1.1 Embankment on soft clay treated with sand drains (Queyroi et al., 1977)

A 6-meter-tall and 900-meter-long highway embankment was built. The organic clay strata have a crust that is about one metre thick and are exceedingly flexible. Ten metres of organic, malleable, soft clay. Different kinds of foundation soils are shown by profiles PL1 and PL4. At each location, a triangle mesh was set up with sand drains that had outer and

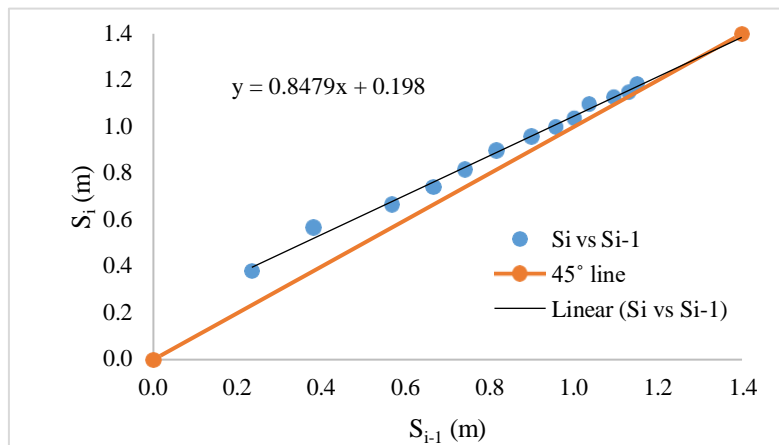
inner diameters of 0.3 m and 0.1 m, respectively, spaced 2.0 m apart.

#### 1.1.1 Profile PL1

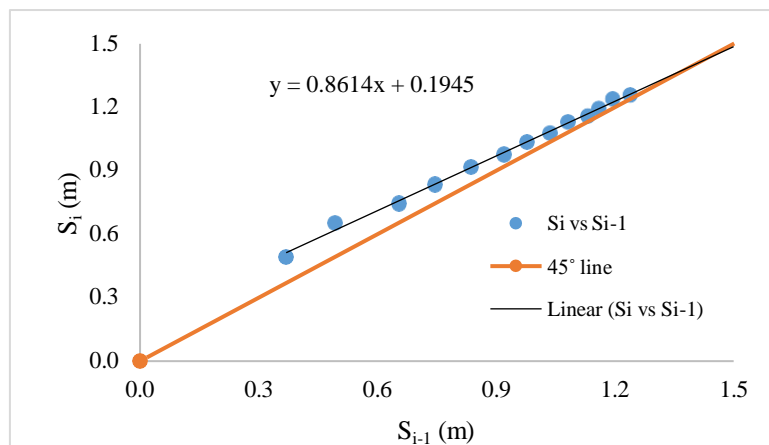
Piezometers and settlement gauges were used to instrument the PL1 profile. The unit cell diameter ( $d_e$ ) to the well diameter ( $d_w$ ) ratio is 7.0. Figure 8 shows the time-settlements that were observed at points T1, T2, and T3.

**Fig. 8** In-situ time-settlement plots at PL1 site (Queyroi et al., 1977)

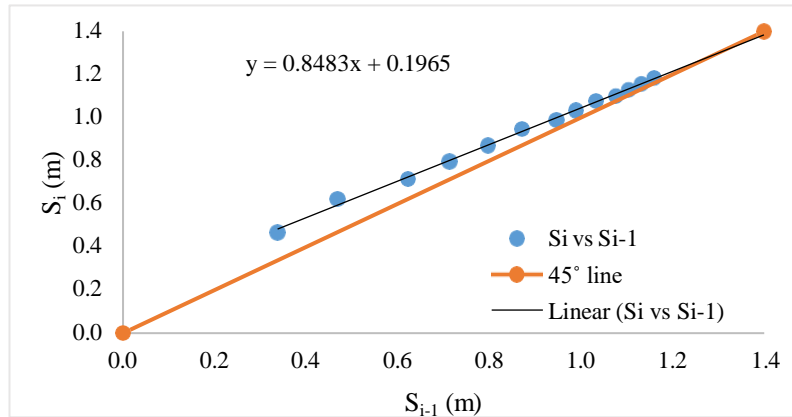
Ultimate settlements estimated from Asaoka plots shown in Figs. 9, 10 and 11.



**Fig. 9** Asaoka plot at T1, Profile PL1



**Fig. 10** Asaoka Plot at T2, Profile PL1



**Fig. 11** Asaoka plot at t T3, Profile PL1

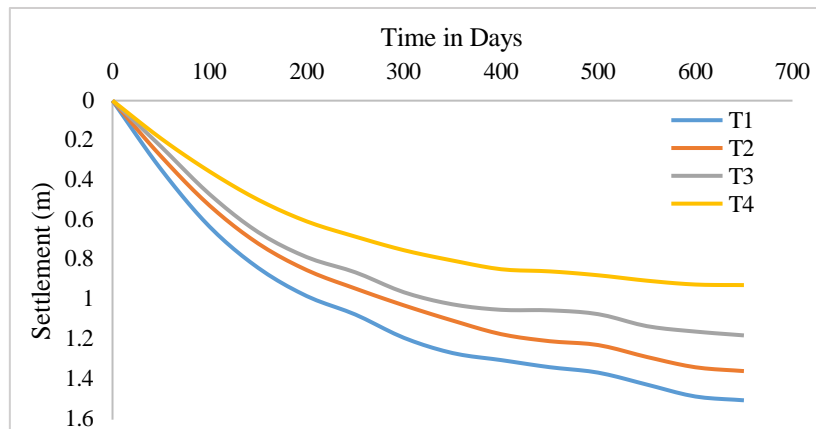
Settlements,  $S_{t0}$ , and time  $t_0$ , for end of construction, final settlements,  $S_{ult}$ , degrees,  $U_{r(t0)}$ , of consolidation and time factors,  $T_{R0}$ , corresponding to end of construction are determined and listed in Table 1 for the three points for Profile PL1.

**Table 1** Parameters for Profile PL1

Profile	$S_{t0}$ (m)	$t_0$ (days)	$S_{ult}$ (m)	$U_{r(t0)}$	$T_{R0}$
T1	1.05	500	1.3	0.81	0.8
	3			0	0
T2	1.08	500	1.4	0.77	0.6
	4			5	8
T3	1.13	500	1.3	0.87	1.2
	2			1	5

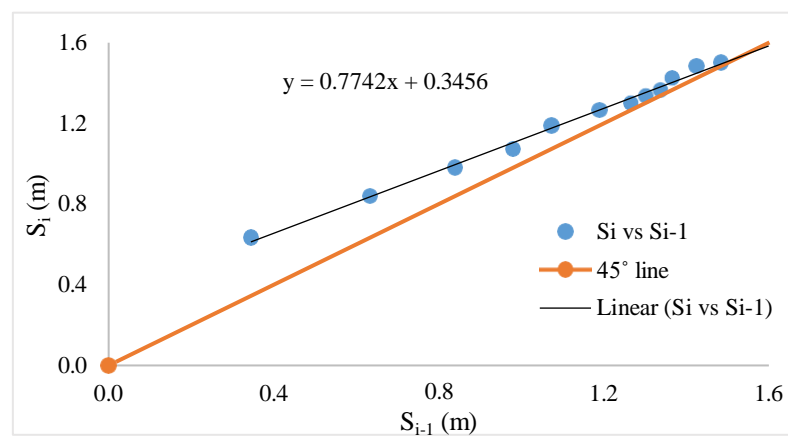
**1.1.2 Profile PL4**

There are five surface settlement plates placed at various locations on the ground at PL4. This is shown in Figure 12 by means of in situ time-settlement graphs at points T1, T2, T3, and T4 for the PL4 profile.

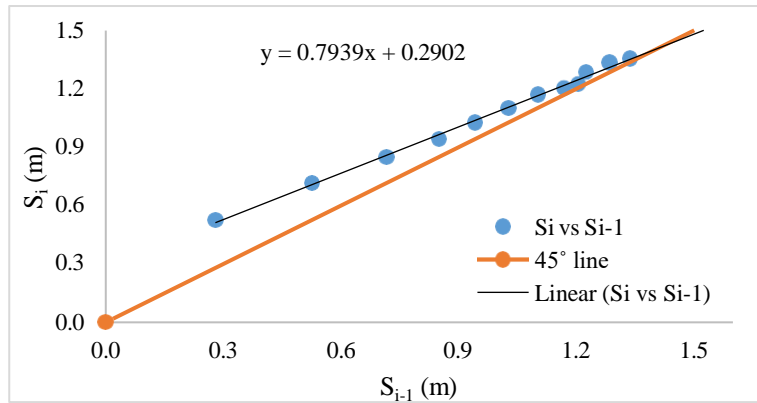


**Fig. 12** Observed In-situ Time-settlement plots at PL4 (Queyroi et al., 1977)

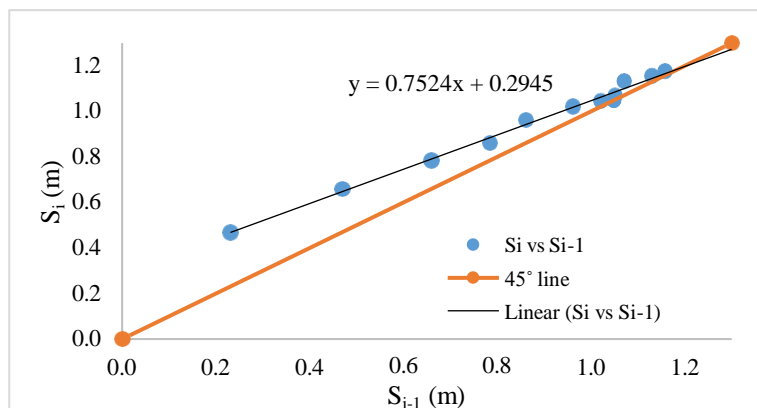
See Figures 13–16 for the final settlements, and the  $S_{ult}$  computed from the time-settlement curves using the Asaoka plots.



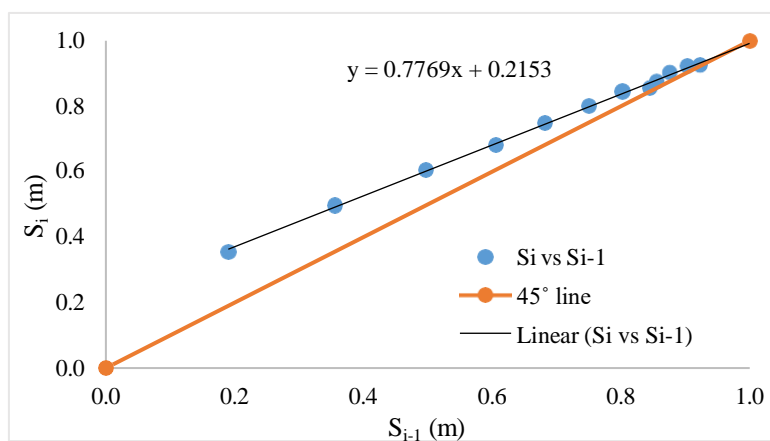
**Fig. 13** Asaoka plot at point T1 of profile PL4



**Fig. 14** Asaoka plot at point T2 of profile PL4



**Fig. 15** Asaoka plot at point T3 of Profile PL4



**Fig. 16** Asaoka plot at point T4 of profile PL4

The parameters for the Si Vs Si-1 figure are as follows: unit cell diameter ( $d_e$ ) = 2.1 m, well diameter ( $d_w$ ) = 0.3 m, ratio ( $n$ ) = 7.0 between drain and well diameters,  $F(n)$  = 1.598, and a time interval ( $\Delta t$ ) of 50 days. Table 2 displays the parameters for Profile PL4.

**Table 2** Parameters of Profile PL4

Dept h (m)	$S_{t0}$ (m)	$t_0$ (days)	$S_{ult}$ (m)	$U_{r(t_0)}$	$T_{R0}$
<b>T1</b>	1.364	500	1.50	0.909	1.80
<b>T2</b>	1.226	500	1.36	0.901	1.75
<b>T3</b>	1.071	500	1.16	0.923	2.05
<b>T4</b>	0.868	500	0.96	0.904	1.60

The two profiles PL1 and PL4's estimated coefficients of consolidation for radial flow,  $c_{vr}$ , are shown in Table 3 and are obtained by plugging the relevant parameters into Eq. 6.

**Table 3**  $c_{vr}$  for Profiles PL1 and PL4

Profile PL1		Profile PL4	
Point	$c_{vr}$ (m <sup>2</sup> /yr.)	Point	$c_{vr}$ (m <sup>2</sup> /yr.)
T1	2.58	T1	5.79
T2	2.19	T2	5.63
T3	4.02	T3	6.60
		T4	5.15

## 2 Results and Discussion

The laboratory test results for the Mud flats site show radial flow coefficients ( $c_{vr}$ ) ranging from 0.95 to 9.47 m<sup>2</sup>/year (Al Alusi et al., 1977), but the in situ coefficients ( $c_{vr}$ ) estimated using the proposed degree of consolidation at the end of construction range from 2.63 to 5.05 m<sup>2</sup>/year, which is significantly different from the values determined in the laboratory.

The laboratory coefficients of consolidation for the treated ground site at profiles PL1

and PL4 range from 4.73 to 37.87 m<sup>2</sup>/year (Queyroi et al., 1977). On the other hand, the proposed new approach estimates the in situ coefficients of consolidation for radial flow based on the degree of consolidation at the end of construction time, which range from 2.19 to 4.02 m<sup>2</sup>/year for profile PL1 and 5.15 to 6.60 m<sup>2</sup>/year for profile PL4. Coefficients calculated in the lab and those found in the field diverge significantly, once again. Laboratory results derived from tiny samples do not reflect the real-world behaviour of the ground.

### 3 Conclusion

The in-situ consolidation process may be expedited with the use of PVDs or sand drains with a surcharge. Using in-situ time-settlement plots from the beginning, the suggested

technique calculates the radial flow's coefficient of consolidation. Values calculated in the lab and those estimated from the in situ time-settlement plot don't match up.

### References

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