WICK DRAIN PERFORMANCE AT A SITE IN EAST RICHMOND, B.C.

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Preloading and wick drain performance on a site located in east Richmond, B.C., on the South Arm of the Fraser River, is reviewed with the objective of determining wick drain effectiveness and identifying some aspects relevent to successful performance in soft to firm, clayey silts, typical of the Fraser River delta. For a wick drain spacing of 2 m the settlement rate is increased by about 2 to 5 fold. Approximate back analyses of the settlement records for sites with and without wick drains indicates similar values for vertical and horizontal coefficient of consolidation is close to unity. We consider this to be due to smear caused by the mandrel during installation of the wick drains.

INTRODUCTION

Wick drains are primarily used to accelerate consolidation of compressible, fine grained soils by shortening the path length required for dissipation of excess pore pressure resulting from the application of a surcharge load. However, published case histories sometimes provide overly optimistic indications of wick drain effectiveness by comparing settlement monitoring data from sites with wick drains, with theoretical estimates of consolidation time for sites without wick drains. This paper addresses this aspect by quantifying wick drain effectiveness in the soft to firm, clayey silts of the Fraser River delta, by comparing settlement records from adjacent sites with and without wick drains. Some aspects relevant to wick drain performance, are also discussed.

The site considered is a business park development located in east Richmond, B.C., where large 2-storey office and warehouse buildings are being constructed. Without preloading, settlements (total and differential) of typical structures were expected to be unacceptably large, and preloading was, therefore, specified to limit settlement to tolerable amounts. Wick drains were used to reduce preload durations on several lots where construction scheduling requirements did not allow for the 12 to 24 months or more, typically required for preloading. Site layout is shown in Figure 1.

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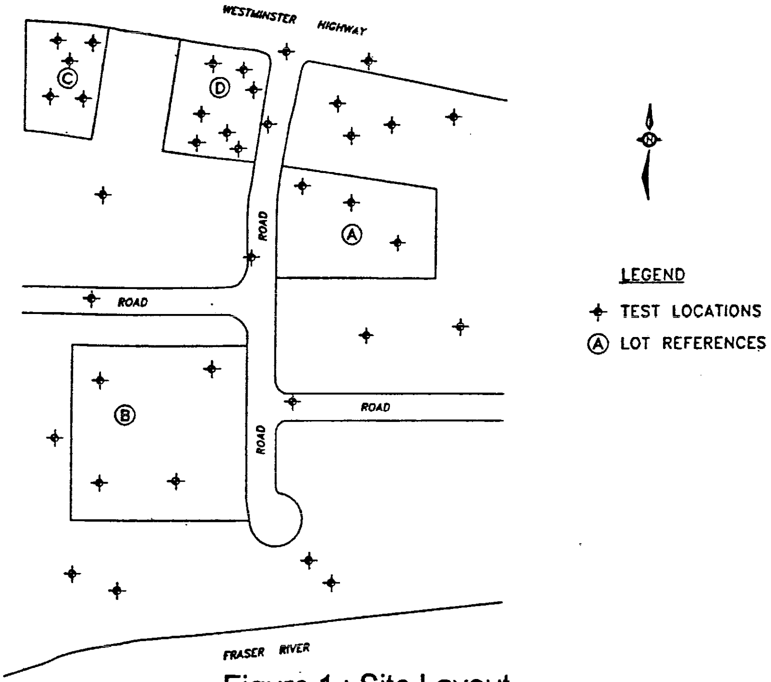


Figure 1 : Site Layout

SOIL CONDITIONS

General Soil Profile

The general soil profile prior to preloading, typically comprised site grading fill, over variable thicknesses of peat, organic silt and clayey silt, over loose to compact (becoming compact to dense with depth) sand with occasional silt lenses. The sand layer extends to about 30 m below ground and overlies deep interlayered deposits of normally to slightly over consolidated, clayey silt, sandy silt and silty sand, which reportedly occur to depths of up to 300 m.

Table 1 : Simplified Stratigraphy above Native Sand Layer

Lot	Mean Depths of Layers (m)			
	Site grading fill	Peat/Organic silt	Clayey silt	Sand
A	0 - 4.3	4.3 - 7.8	7.8 - 16.3	+ 16.3
B	0 - 3.7	3.7 - 5.6	5.6 - 16.2	+ 16.2
C	0 - 2.2	2.2 - 2.4	2.4 - 16.0	+ 16.0
D	0 - 2.5	2.5 - 4.9	4.9 - 16.0	+ 16.0

The site grading fill consisted mainly of sand, which had been in place for at least 8 years.

The peat and organic silt layers are soft to firm in consistency, and the peat is dark brown and fibrous.

The clayey silt is typically normally consolidated, slightly to moderately (sometimes highly) cohesive, and soft to firm in consistency, with organic silt and organic rich layers. In places the clayey silt is very soft to depths of about 10 m, and soft to firm below.

Although the deep, interlayered silty deposits below the sand layer are compressible and would be subject to significant long-term settlement under fills, they were not investigated in detail, because they would be only slightly influenced by building loads, and would contribute relatively little differential settlement.

Groundwater typically occurs at depths ranging between 1 and 2.5 m below existing grades, but probably fluctuates in response to rainfall and drainage conditions.

Engineering Parameters of the Upper Compressible Soils

Moisture contents and undrained shear strength from vane shear tests in the upper compressible layers are plotted against depth in Figures 2 and 3.

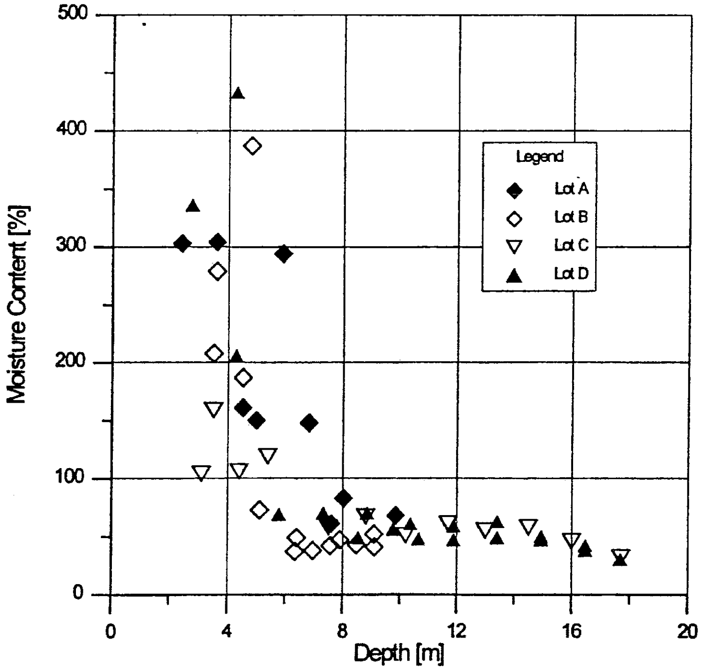


Figure 2. Variation in Moisture Content with Depth

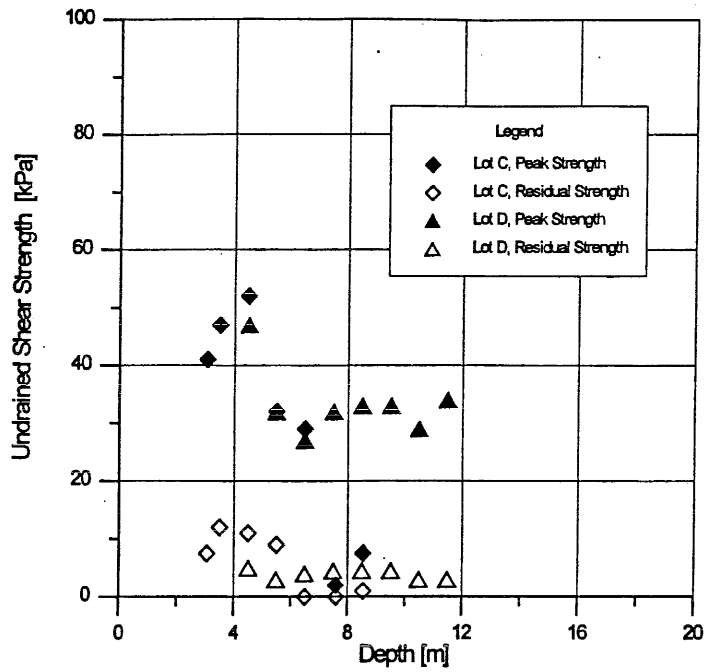


Figure 3. Variation in Undrained Shear Strength with Depth

Figure 2 shows moisture content variations between 100 and 400%, and 37 to 100% in the peat/organic silt and clayey silt layers, respectively. Peak undrained shear strength varies between about 5 and 50 kPa, and the remedial strength is typically less than 10kPa.

Atterberg limits and clay fraction for the clayey silt are summarized below:

Liquid limit = 45 - 68%
Plasticity limit = 27 - 38%
Clay fraction = 13 - 22%

Moisture contents are typically equal to or greater than the liquid limit, indicating compressible and probably sensitive soils. Experience shows these soils are subject to significant secondary compression.

Consolidation parameters have been determined in the laboratory on a few relatively undisturbed samples recovered during drilling and from pore pressure dissipation tests using the piezometer cone penetration test (CPTU). Values obtained are as follows:

C_c (laboratory testing)	0.37 to 0.47
C_v (laboratory testing)	16 to 40 m^2/year
C_h (CPTU testing)	10 to 15 m^2/year

These values are just outside the range of typical values of 0.3 to 10, and 1.5 to 16 m^2/year for normally consolidated clays and clayey silts/silty clay, respectively.

WICK DRAIN SPECIFICATION AND DESIGN

Wick drains (Mebra Drain MD-7407) were supplied by Nilex of Vancouver, B.C., and consisted of continuous plastic drainage core wrapped in a non-woven, polypropylene geotextile jacket. Specifications for the Mebra Drain are as follows:

• Width	100 mm
• Thickness	3.4 mm
• Water discharge capacity	
@ 10 kN/m^2	140 x 10^{-6} m^3/sec
@ 300 kN/m^2	105 x 10^{-6} m^3/sec
• Filter permeability	0.171 mm/sec
• Permittivity	0.45 /s
• Apparent Opening Size (AOS)	120/140 (sieve #)

The following simplified equation given in the Canadian Foundation Engineering Manual (1992), was used to determine wick drain spacing:

(1)
$$t = \frac{D_e^2}{8C_h} \times \left(\ln\frac{D_e}{d} - 0.75\right) \times \ln\left(\frac{1}{1-U_h}\right)$$

where:

t = time from start of consolidation
D_e = zone of influence of a drain, = 1.05D for triangular layout
d = equivalent diameter of a drain
U_h = average degree of horizontal consolidation
C_h = coefficient of horizontal consolidation

Provision can be made in the above equation to correct for soil disturbance and drain resistance, but for the purposes of this assessment "ideal" conditions have been assumed. The above equation was developed for circular sand drains, but can be extended to wick drains using a modified diameter, based on equalizing the perimeter of the wick drain with that of a circular drain of the same perimeter. Recent evaluations (Long and Covo (1994)) using analog field plotters suggest the following relationship for equivalent diameter, d:

(2)
$$d = 0.5b + 0.7t$$

where:

b = drain width
t = drain thickness

However, Crawford et al (1992) show that variations in d have relatively small influence on predicted consolidation time.

PRELOAD DIMENSIONS AND WICK DRAIN INSTALLATIONS

The peat/organic silt and clayey silt were most relevant to the proposed site development, but only the silt layers were targeted for improvement by wick drains. Table 2 summarizes preload dimensions and heights and provides information on wick drain installations:

Table 2. Preload Dimensions

Lot	Improvement method	Dimension (m)	Preload height (m)
A	Preloading	40 x 90	3.2 to 3.3
B	Preloading	100 x 115	2.6 to 3.0
C	Preloading with Wick Drains	40 x 50	3.4 to 3.7
D	Preloading with Wick Drains	30 x 30	5.3 to 5.5

The wick drains were installed on a 2 m triangular grid with a static mandrel to about 16 m depth, the maximum possible with the equipment used. Drain spacing was selected to achieve about 80% consolidation in 3 to 6 months. As weak zones were encountered at several locations, the preload was generally placed in 2 stages, with about 30 days between stages.

SETTLEMENT MONITORING RESULTS

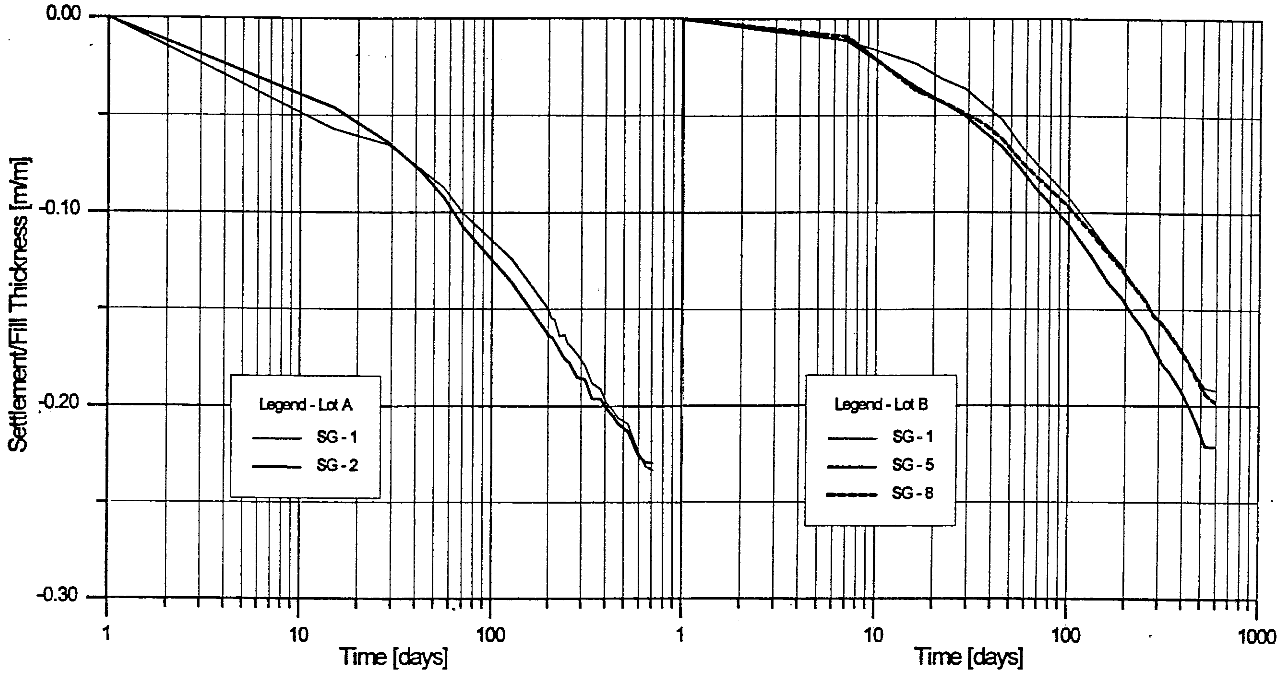
General

Settlement-time records based on a normalized settlement given by the S/H ratio (namely, settlement to increment in fill height placed above site grading fill), are provided in Figures 4a through 4d. Data is provided from several gauges on each site to indicate variability.

The decision to remove the preload is often based on the degree of consolidation, but this is difficult to estimate accurately. For this project the hyperbolic plotting approach (Tan (1994)) and the Asoaka method (Holtz et al (1991)) were used. However, these methods are difficult to apply as secondary compression masks the primary consolidation. Practical approaches developed for routine use are discussed in Tara and Hall (1995). Based on our work and for the conditions present, we estimate that 90% consolidation likely corresponds approximately to S/H = 0.23 to 0.25.

Lots A and B : No Wick Drains

Both lots, which do not have wick drains (Figures 4a and 4b), show similar settlement responses over the approximately 2 years of record with little variation between results. A very rough estimate of the coefficient of vertical consolidation is between 7 and 12 m²/year. Time to reach S/H = 0.24 is about 750 and 1100 days, on Lots A and B, respectively.

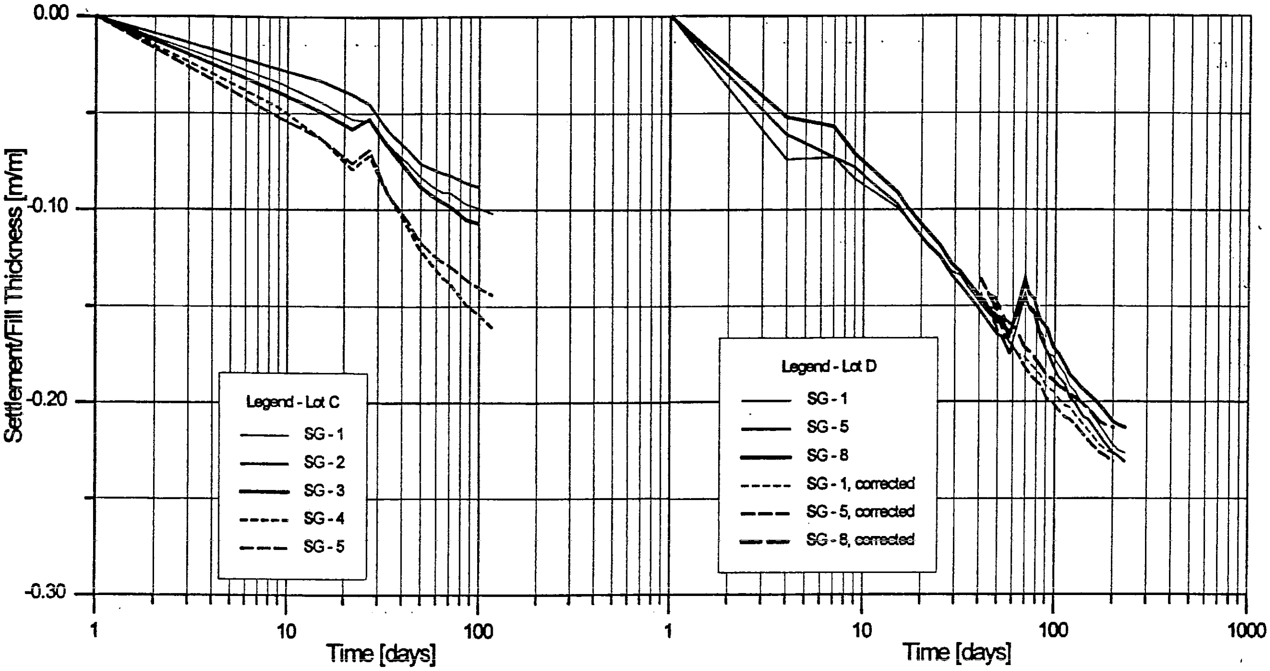


Figures 4a and 4b. Settlement-time Records for Lots without Wick Drains

Lots C and D : With Wick Drains

Settlement plots for Lot C (see Figure 4c) show two distinct responses, and a slowing of settlement rate can be seen after about 60 days for some of the gauges, which is typical of sites without significant deposits of peat and organic silt. The large variation in settlement is believed to be due to variable geotechnical conditions. Ideally this slowing in settlement rate is the anticipated break in the settlement curve, signifying the end of primary consolidation. However, it is also possible that clogging/failure of the wick drains is occurring. It was anticipated that pneumatic piezometer monitoring would have provided insight into this aspect, but unfortunately the pore pressure monitoring results were inconsistent and generally showed only small reductions with time and were difficult to interpret.

The results for Lot D (Figure 4d), unlike Lot C, fall within a narrow band, which we generally attribute to relatively uniform geotechnical conditions and to equalizing of the drainage by the wicks. The step in the curve represents stage loading of the fill. These curves are corrected in Figures 4d and 5 to remove the step.



Figures 4c and 4d. Settlement-time Records for Lots with Wick Drains

A very rough estimate of the coefficient of horizontal consolidation is between 4 and 12 m^2/year. Time to reach S/H = 0.24 is about 200 to 300 days on Lot D.

DISCUSSION

Effectiveness of Wick Drains

Figure 5 compares typical normalized results from each site, and shows that the wick drains accelerate settlement by between 2 and 5 fold. In both sites with and without wick drains the settlement-time curves become parallel, presumably reflecting the stage at which secondary compression predominates. The slower settlement rate in some gauges on Lot C appears to be consistent with experience at other nearby sites where little or no organic soils occur.

The very rough back calculations given previously indicate the ratio of C_h to C_v tends to unity. We believe this results from smear caused by the mandrel used for the installation.

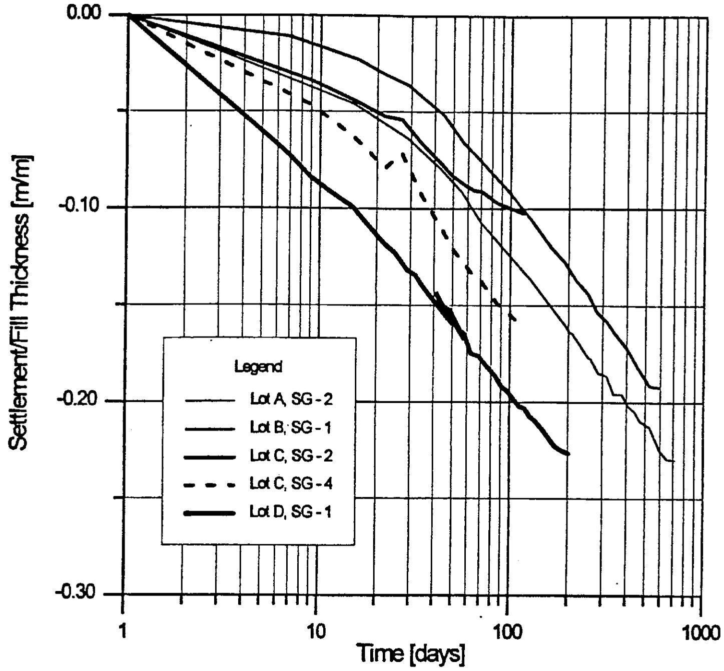


Figure 5. Comparison of Representative Settlement Records from each Lot

Potential for Clogging

Little mention is made in the literature regarding clogging of wick drains, but the reported satisfactory performance of wick drains on other projects in the Lower Mainland (Robinson and Eivemark (1989)), suggests clogging is not a problem. Clogging occurs either by fines blocking the geotextile filter jacket and preventing water entering the drain (filter opening too small), or alternatively by excessive fines moving through the filter and blocking the drainage core (filter too large). Soil disturbance around the wick drain can lead to changes in soil permeability and may also influence clogging.

For the site studied the gradation parameters of the clayey silt are as follows:

d_{85} size = 0.019 to 0.028 mm
d_{50} size = 0.006 to 0.009 mm
Passing #200 sieve = 90 to 100%
Uniformity coefficient = 7.5 to 15

CFEM (1992) and Koerner (1990) indicate for soils with more than 10% passing the #200 sieve, the Filtration Opening Size (FOS) of the geotextile should be less than 0.3 mm. However, there appears to be some doubt as to the reliability of this approach, and most authorities suggest the following:

- FOS less than 1 to 3 times d_{85}
- FOS not less than 0.04 mm

These equations require FOS values approximately equal to AOS of between 0.02 to 0.08 mm, which are significantly less than the pore size opening of 0.110 mm for the Mebra Drain installed on Lots C and D. We plan to evaluate whether clogging may be playing a role in drain performance by retrieving and inspecting sections of drain, on completion of preloading at one of the sites.

Flow Capacity

CFEM (1992) draws attention to the need for sufficient flow capacity within the wick drain in order to avoid pressure build up, which could slow the consolidation rate and encourage premature preload removal. If all water expelled from the soil during the first 10 days of consolidation flowed from the top of the wick, the flow would have been about 0.13 litres/minute. Even after applying a factor of safety to allow for kinking and compression of the drain as suggested by Koerner (1990), the flow is well within the recommended flow capacity of 0.72 litres/minute. Therefore, flow capacity is apparently not a major consideration for the conditions at these sites.

CONCLUSIONS

This case history shows for the compressible soils present, wick drains installed on a 2 m triangular grid accelerate consolidation by between 2 and 5 fold. Determination of the degree of consolidation is difficult to estimate, and additional investigations are needed to develop methods for routine use.

Our rough back calculations show the ratio of C_h to C_v is approximately equal to unity. We believe this is due to smear caused during installation of the wick drains. Therefore, improved installation methods could improve the effectiveness of the wick drains. However, for design purposes standard corrections for soil disturbance as discussed by Crawford et al (1992) should be used.

The results also indicate that clogging of the drain by fines passing through the filter jacket and blocking the drainage core, should be considered in the Fraser River delta silts.

The settlement data presented is relatively short term and does not allow evaluation of the influence of preloading and accelerated consolidation by wick drains, on secondary compression. However, CFEM (1992) indicates that wick drains are particularly suitable for soft clays, but have little effect on soils with relatively small primary but large secondary effects, such as peat and organic silt.

ACKNOWLEDGEMENT

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