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Field performance of in-line flocculated fluid fine tailings using thin lift deposition

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Abstract

Dewatering of in-line flocculated (ILF) oil sands fluid fine tailings (FFT) using organic polymers with thin lift deposition is discussed in this paper. The tests were conducted at Syncrude's Mildred Lake Settling Basin near Fort McMurray, Canada, between August and October 2010. Matric suction measurements in sand foundation materials underlying ILF-FFT showed that it required approximately 21 days following deposition for the suctions to return to the initial values. Results for evaporation measurements from mini-lysimeters (4" diameter) samples obtained from deposit in Cell 32 revealed that it required approximately 21 days for the ratio of actual evaporation to potential evaporation (AE/PE) to reach a residual value of 0.2 (20%). In summary, results obtained during this study indicated that dewatering of the ILF-FFT thin lift layer is due to both atmospheric drying and downward drainage to the foundation materials underlying the deposit.

1 Introduction

Oil sands mining operators such as Syncrude Canada Ltd. produce large volumes of tailings. Disposal of these tailings is presently managed in external disposal ponds. The tailings slurry is generally comprised of a warm aqueous suspension of sand, silt, clay, residual bitumen, salts, surfactants and naphtha at a pH typically between 8 and 9. The resulting discharge flow segregates, with the coarser fraction of the tailings slurry settling out rapidly to form long beaches that become progressively finer. The solids contained in the fresh slurry arriving at the pond settle relatively fast (over several days) creating a "clean" water cap containing little solids. Settling continues to take place below the water cap, and typically within a few days a solid content of 15% by weight is achieved to produce a material called thin fine tails (TFT). Hindered sedimentation continues within the pond, and the TFT within the pond gradually form fluid fine tailings (FFT) which range between 30 and 45% solids by weight depending on depth and time since deposition. Further dewatering and consolidation of the tailings within the pond occurs very slowly because the water chemistry in the tailings is dominated by sodium and chloride, which disperses clay minerals present in the tailings. To improve oil sands tailings facilities' reclamation techniques, alternate methods of managing and reclaiming the FFT are being investigated.

The objective of the research described here, conducted by Syncrude and Total, is to evaluate various methods of dewatering the FFT to increase the solids content for increased shear strength. Methods of dewatering being investigated include in-line flocculation (ILF) followed by thin lift deposition, as well as flocculation and centrifugation (FC) of FFT to produce a cake like material (53% by weight) that is placed in thicker layers using conveyors and trucks. The present study focused on evaluating the performance of the ILF-FFT thin lift deposition dewatering method.

2 Site location and methods

The field scale pilot plant for dewatering Syncrude's FFT is located at the Mildred Lake Settling Basin (MLSB) (57° 39' N, 111° 13' W) which is 40 km north of Fort McMurray, Alberta, Canada. The climate is classified as sub-humid continental, which is characterised by cold winters and warm summers. Thirty-year climate normals (1971–2000) for Fort McMurray indicated daily temperature for January and July are -18.8

and +16.8 C°, respectively. Mean annual precipitation is 456 mm, of which 342 mm occurs as rainfall. The majority of rainfall (67%) occurs between June to August largely as convective storms with high intensities and short durations.

2.1 Coupons and cells constructions

Several bermed deposition coupons and cells measuring between 5 x 10 m and 50 x 100 m, respectively, were constructed on graded sand beaches (Figure 1) and filled with ILF-FFT at beach slopes ranging from 0.5 to 2%. Thin lift layers of ILF-FFT of variable thicknesses ranging between 100 and 500 mm were placed within the coupons and cells during August and September 2010. Extensive instrumentation was installed to measure dewatering rates due to atmospheric drying and downward drainage to the foundation materials underlying the deposited lifts. The instruments installed included jet fill tensiometers, soil moisture probes, piezometers and mini-lysimeters.

Figure 1 Construction and instrumentation of a sand bermed cell (50 m x 100 m)

2.2 In-line flocculated fine fluid tailing (ILF-FFT) deposition

ILF involves the injection of the flocculant into the pipeline at a given distance upstream from the discharge point to allow the required mixing and contact to take place within the pipe. Mixing and shear during transportation allow the formation of clay floc. The slope of the depositional beach promotes immediate dewatering by ensuring that the decant waters rapidly drain to the toe of the thin lift layer as the tailings settle. Further dewatering continues through drainage and evaporation. After the effluent runoff flows away from the deposit, further dewatering continues over the long term through drainage and evaporation (Wells et al., 2011).

2.3 Suction measurements

The jet fill tensiometers (Figure 2) were installed to measure suction changes with time in the sand foundation materials for the coupons and cells prior to ILF-FFT deposition. A jet fill tensiometer consists of a porous ceramic tip on the bottom, a vacuum gauge near the top, and a sealing cap attached to a tube which is inserted at specific depths in the soil. The vacuum gauge provides a direct measurement of the soil suction. Several nests of three tensiometers each were installed in the coupons and cells at depths of 150, 250 and 400 mm by using conventional soil sampling tools. A total of 42 tensiometers were installed in the coupons and cells to monitor the changes in suction in the sand foundation material after ILF-FFT deposition between August and October 2010. Measurements were obtained once per day.

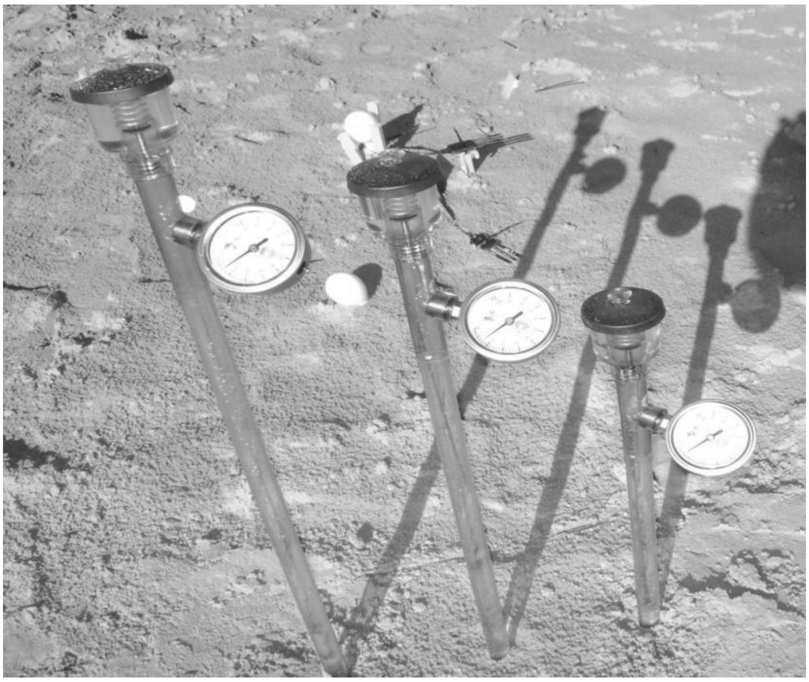

Figure 2 A nest of three tensiometers and soil moisture probes installed in foundation sand beach at depths of 150, 250 and 400 mm within a cell

2.4 Evaporation measurements

To measure evaporation rates across the surfaces of the cells, mini-lysimeters were constructed from 4” diameter PVC casing with the bottoms fitted with PVC or plastic caps (Figure 3). Undisturbed ILF-FFT core samples were collected directly from the coupons and cells by pushing the open-ended cylinder into the surface of the ILF-FFT deposit. The caps (~5 cm height) were half-filled with the sand foundation material collected at the sampling stations before being fitted to the lysimeters. Monitoring of changes in lysimeter weight was performed daily at regular time intervals using a weighing balance. Evaporation measurements were monitored under natural atmospheric conditions (outside). The air temperature around the lysimeters was measured prior to the weighing using a thermometer.

Figure 3 A set of 4” diameter PVC lysimeters used for evaporation measurements

2.5 Hydraulic conductivity and shear strength measurements

The Guelph permeameter (Figure 4) was used to obtain measurements of hydraulic conductivity in the ILF-FFT deposits. The Guelph permeameter is a constant head permeameter that measures in situ hydraulic conductivity. The hydraulic conductivity governs how water flows through a saturated/unsaturated soil profile. The method involves measuring the steady-state rate of water recharged into unsaturated soil from a 2” cylindrical hole, in which a constant head of water is maintained. The Guelph permeameter is a complete kit consisting of the permeameter, field tripod, well auger, well preparation and clean up tools, collapsible water container, and vacuum test hand pump all packaged in a durable carrying case.

Shear strength measurements were performed using a portable shear strength device to test the ILF-FFT deposits to determine their relative strength profiles.

3 Selected results

Selected observations and results related to matric suction, evaporation and measured shear strength are summarised below.

3.1 Study of the ILF-FFT deposit from Cell 32

3.1.1 Water released on deposition

The amount of runoff (a component of the dewater balance) that occurred due to flocculation and deposition was not directly quantified in this study. The runoff could be assumed to be in the range of 28 to 35% of the dewatering.

Figure 4 Measurements of hydraulic conductivity on the 2009 ILF-FFT deposit in Cell 3 at Syncrude’s Mildred Lake Settling Basin using a Gulph permeameter

3.1.2 Measured suctions

Figure 5 presents selected results of suctions measured in the sand foundation material at Station 1 in Cell 32 at depths of 150 and 250 mm from 2 September to 18 October 2010 during the field trial. It should be noted that during the ILF-FFT deposition in Cell 32, the gauge for the tensiometer at the greatest depth (i.e. 400 mm deep) was submerged below the surface of the ILF-FFT deposit, and no observations were collected during the field trial. The daily average temperature measured from a weather station is also plotted on the same figure.

Results presented in Figure 5 (Lines A and B) show that prior to the ILF-FFT deposition in Cell 32 on Day 1 (2 September 2010), the pre-deposition suction values at the near ground surface (150 mm deep) and 250 mm deep in the sand foundation material were 7 and 6 kPa, respectively. Following the IFT-FFT deposition on Day 2 (3 September 2010), the suction at the near ground surface (150 mm deep) decreased rapidly from 7 to 2 kPa (Line A), whereas the suction rate at a greater depth (250 mm deep) (Line B) decreased slowly from 6 to 5 kPa with time. The change in suction for both tensiometers remained low for a period of about 10 days. The rapid decrease in suction at the near ground surface (150 mm deep) is attributed to rapid downward drainage of water released from the ILF-FFT deposit on the sandy texture of the foundation material. It is also suggested that during downward drainage, water is simultaneously redistributing deeper into the beach sand profile due to the capillary forces and gravity, thereby accelerating drainage to greater depths below 250 mm. The time-variable rate of redistribution depends not only on the hydraulic properties of the sand foundation material, but also on the initial wetting depth as well as on the relative dryness of the bottom layers (Capehart and Carlson, 1997; Kabwe et al., 2005).

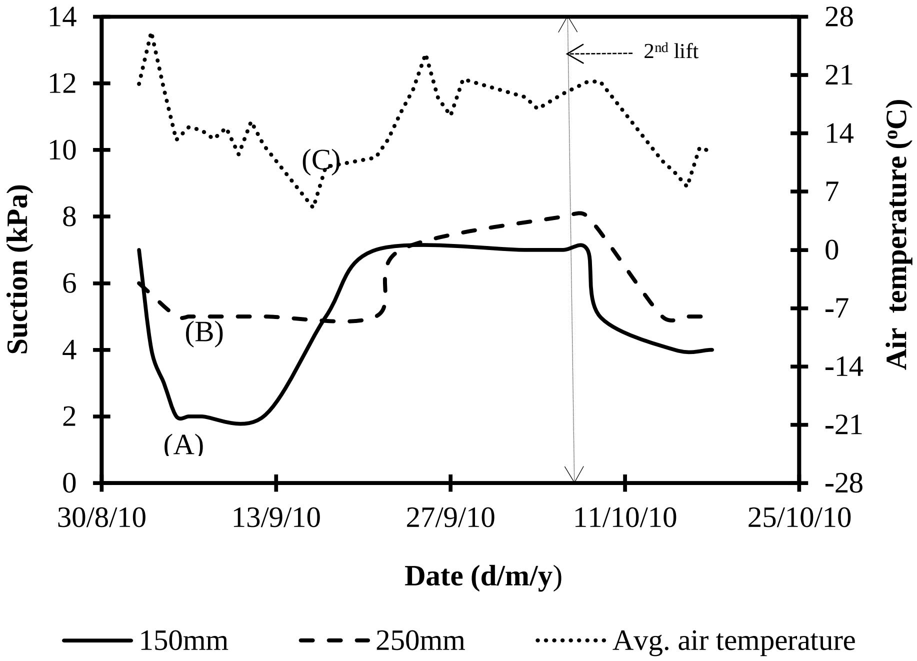

Figure 5 Changes in matric suctions (kPa) versus time measured with tensiometers installed in the sand foundation material at depths of (A) 150 mm and (B) 250 mm within Cell 32 from 2 September to 18 October 2010. Line C represents data for the average daily measured air temperature (°C)

After Day 12, the suction at a depth of 150 mm started to increase and eventually reached its pre-deposition suction value of approximately 7 kPa and remained higher over an extended period of 21 days. The suction at a greater depth (250 mm deep) also exhibited a similar pattern, but with reduced amplitude. It should be noted that after the initial 21-day test period, the surface of the deposited thin lift in Cell 32 became relatively dry and desiccated (Figure 6B). A second lift was then deposited on top of the first deposit in Cell 32 on 5 and 6 October 2010 (Figure 6B), and results in Figure 6 also show that both suction rates at depths of 150 and 250 mm decreased once again after deposition of the second lift.

In summary, the downward drainage of water released from the ILF-FFT deposit to the sand foundation material was initially most rapid at the near ground surface (0–150 mm depth) with a progressive decay at greater depths (250 mm and below) due to the free-draining texture of the sand foundation material. Results showed that it required approximately three weeks for suction to return to the initial values following the deposit of ILF-FFT, depending on the drainage and actual evaporation rates.

3.1.3 Water contents

Results of measured gravimetric water contents (Line A) in the sand foundation material along with changes in suction (Line B) with time at the near ground surface (0–150 mm) in the sand foundation material of Cell 32 are shown together in Figure 7 for comparison. Results showed that the water content rapidly increased from 6.6% (1 September 2010) to achieve its highest level of 18% (6 September 2010) over a five-day period (6 September 2010) following ILF-FFT deposition. The water content declined rapidly from 18 to 8% over a two-day period (6 to 7 September 2010), and then the drying rates continued to gradually diminish with time and reached its pre-deposition value of approximately 7% after 22 days (22 September 2010). This rapid drainage is also attributed to the sandy texture of the foundation material.

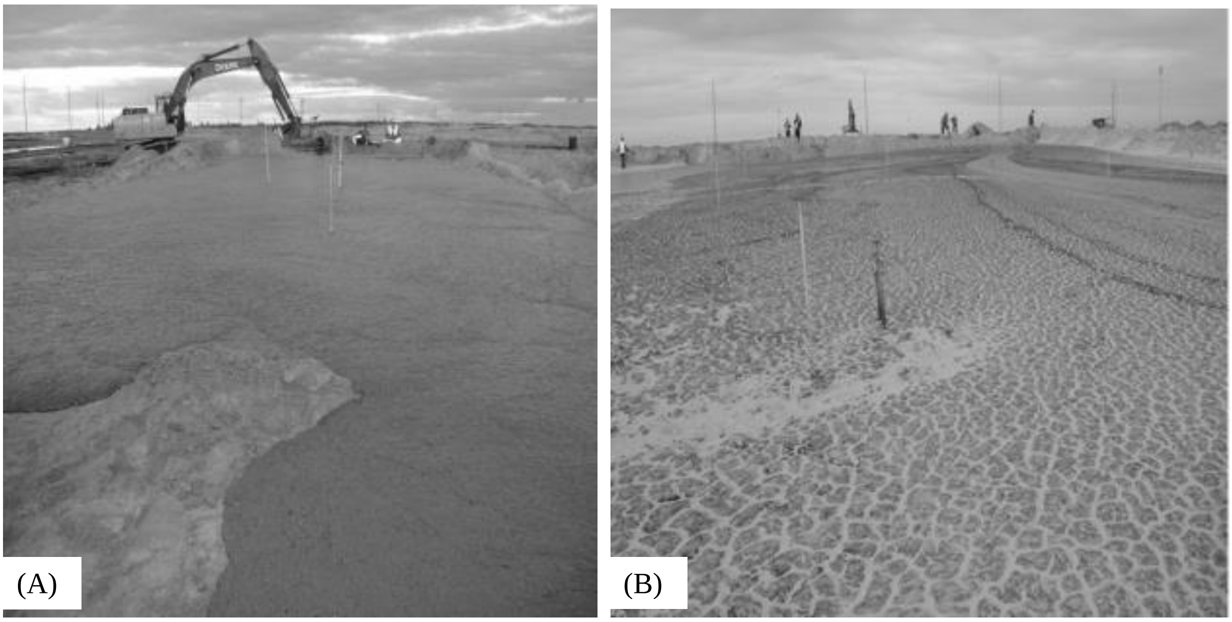

Figure 6 Surfaces conditions of the ILF-FFT deposit in Cell 32 on (A) Day 1 (2 September 2010) and (B) Day 27 (29 September 2010) following the first lift deposit and the onset of the second lift deposition (5 October 2010)

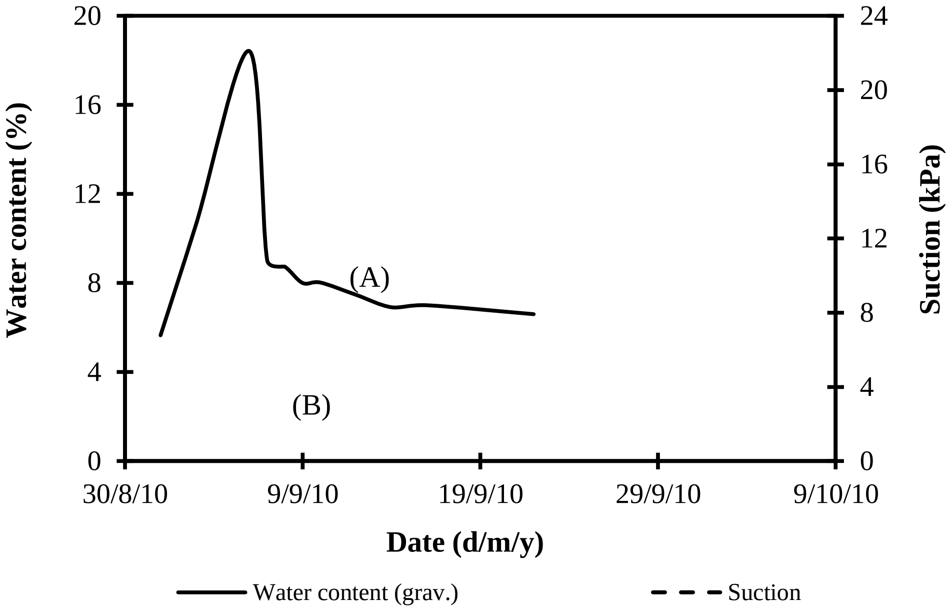

Figure 7 (A) changes in gravimetric water contents and (B) suction with time measured in the sand foundation material from Cell 32 from 1 September to 8 October 2010

Similarly, results showed that the changes of measured suction at the near ground surface (150 mm deep) with time negatively correlated with the measured gravimetric water contents in the sand foundation material (Figure 7). As the water content value rapidly increased from 6 to 18%, the corresponding suction value rapidly declined from 7 to 2 kPa over the initial five-day (2 to 6 September 2010) test period and then started to increase to its pre-deposition suction value of about 6 kPa.

3.1.4 Evaporation

Results of four mini-lysimeters from Cell 32 are presented in Figure 8. Samples were collected five days after ILF-FFT deposition in the cell, and measurements were carried out under natural atmospheric conditions (except during rainfall events when the lysimeters were covered) over a period of four weeks starting from 9 September to 9 October 2010. Results showed that during the initial eight-day period (Stage I drying) from 11 to 19 September 2010, the actual evaporation to potential evaporation (AE/PE) ratios were close to unity (100%). During this drying period the surfaces of the lysimeters were wet, and the evaporation rate was controlled by the atmospheric conditions. The AE/PE ratios gradually decreased (Stage II drying) from 19 September to 9 October 2010 to reach a residual value of approximately 0.2 (20%) (onset of Stage III drying). During Stage II drying, the evaporation rate was controlled by the hydraulic properties of the ILF-FFT (Wilson et al., 1994). It is well established that the slope of the Stage II drying depends on the texture of the material (i.e. grain size, soil-water characteristic curve and hydraulic conductivity function).

In summary, results of evaporation measurements from Cell 32 showed that it required approximately 21 days for the AE/PE ratios to complete Stage II drying, as the samples surfaces became progressively drier. It should be noted that it also took the same length of time for the measured suction in the sand foundation material in Cell 32 to reach pre-deposition suction values following deposition of the ILF-FFT lift.

3.2 Study of the 2009 ILF-FFT deposit from Cell 3

3.2.1 Matric suction measurements

Figure 9 presents results of suctions measured at depths of 150, 250 and 400 mm in the 2009 ILF-FFT thin lift deposit (shown in Figure 4) over a period from 22 September to 17 October 2010. Results showed high pre-deposition suction values of 20, 10 and 12 kPa for depths of 150, 250 and 400 mm, respectively, on 22 September 2010 (Day 1). On Day 3 (24 September 2010) following deposition of the second ILF-FFT lift, the suction at the near ground surface (150 mm deep) decreased rapidly from 20 to 12 kPa (Line A) whereas the suctions at greater depths (250 mm deep) (Line B) and 400 mm (Line C) decreased at slow rates with all values approaching similar values of 8 to 10 kPa at the end of the test period on 17 October 2010.

3.2.2 Shear strength and hydraulic conductivity measurements

Shear strength and hydraulic conductivity (k) were measured at the near ground surface (0–150 mm depth) in the 2009 ILF-FFT thin lift deposit of Cell 3, and the measurement results yielded average values of 40.90 ± 10.20 kPa and 1.94 x 10–6 m/s for the shear strength and k, respectively. The measured value of k is characteristic of a fissured material and/or a uniform fine silty sand material.

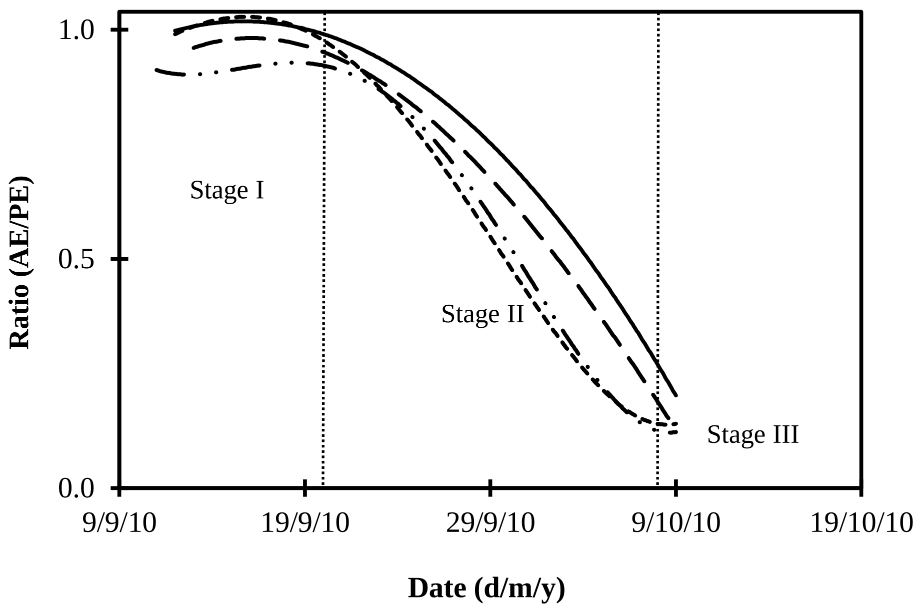

Figure 8 Actual evaporation (AE) and potential evaporation (PE) ratios (AE/PE) as a function of time measured for four mini-lysimeters from ILF-FFT deposit in Cell 32 under natural atmospheric conditions over a period extending from 9 September to 9 October 2010

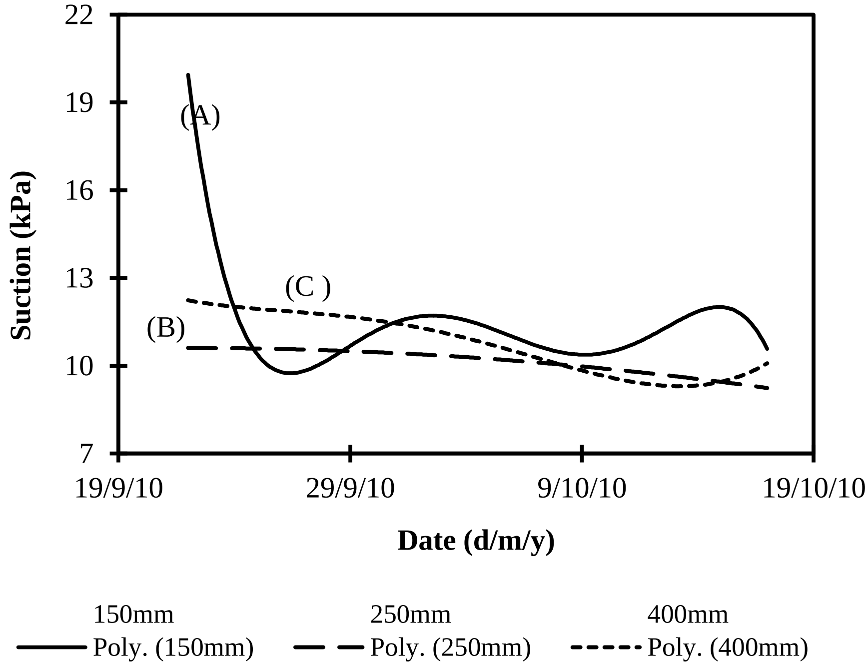

Figure 9 Changes in suction with time measured from 5 September to 18 October 2010, with tensiometers installed in the 2009 ILF-FFT deposit in Cell 3 at depths of 150, 250 and 400 mm

3.2.3 Shear strength and hydraulic conductivity measurements

Shear strength and hydraulic conductivity (k) were measured at the near ground surface (0–150 mm depth) in the 2009 ILF-FFT thin lift deposit of Cell 3, and the measurement results yielded average values of 40.90 ± 10.20 kPa and 1.94 x 10–6 m/s for the shear strength and k, respectively. The measured value of k is characteristic of a fissured material and/or a uniform fine silty sand material.

In summary, the results for the suctions measurements showed that the 2009 ILF-FFT deposit in Cell 3 yielded high suction values of 20, 10 and 12 kPa at depths of 150, 250 and 400 mm, respectively, prior to the second lift deposition. Results also yielded high value of shear strength of 40.9 + 10.20 kPa.

4 Summary and conclusions

The present study showed that downward drainage to the sand foundation material was significant and initially more rapid at the near ground surface (150 mm deep) for the sand foundation material of Cell 32, and decayed with depth (250 mm and below) following the deposition of the ILF-FFT. This is attributed to the sandy texture of the foundation material. Results of the suction measurements showed that it took approximately three weeks for the suctions to return to pre-deposition values after the ILF-FFT deposition. This was attributed to drainage and evaporation rate. Results of the evaporation measurements from Cell 32 showed that it requires approximately 21 days for the AE/PE ratio to reach a residual value (i.e. Stage III drying). At the end of the 27-day test period the surface of the ILT-FFT lift deposit was relatively dry and desiccated.

The one-year-old thin lift deposit in Cell 3 yielded high average suction and shear strength values of 20 and 40 kPa, respectively, at the near ground surface (0–150 mm depth).

Results obtained during this study indicate that dewatering of the ILF-FFT deposit is due to both atmospheric drying and downward drainage to the foundation materials underlying the deposit lifts. However, the amount of runoff due to flocculation and deposition was not quantified in this study. Therefore, accurate measurements of suctions and actual evaporations can provide important complementary information (in addition with the corresponding water content) required to assess the performance of the dewatered ILF-FFT deposits.

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