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INSTRUMENTATION MONITORING FOR HIGHWAY FILL CONSTRUCTION AT IOSEGUN RIVER CROSSING, HIGHWAY 43, NORTHERN ALBERTA

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ABSTRACT
Rate controlled fill placement and installation of wick drains were required for the twinning of a highway across the deep, soft foundation soils of the Iosegun River valley. An instrumentation program was implemented to monitor excess pore water pressures, lateral movements and settlements developed during and after fill placement. Using an observational approach, the rate of fill placement was adjusted according to changes in pore pressure, settlement and lateral movement monitored. Consolidation induced improvement of the strength of the foundation soil within the footprint of the wick drains installation was confirmed by CPT testing undertaken nine months after final completion of fill. The monitored pore pressure and settlement results were in agreement with the predicted values used in design. This paper describes the geotechnical instrumentation program and monitoring results to date. A companion paper in these proceedings presents the results of the geotechnical investigation and mitigation designs for the project.

RÉSUMÉ
Le jumelage d´une autoroute qui traverse les sols de fondation moux et profonds de la vallée de la Rivière Iosegun a nécessité la mise en place du remblai à vitesse contrôlée et l´installation de drains de papier. Un programme d´instrumentation a été mis en place pour mesurer les pressions interstitielles et les tassements induits lors de la mise en place du remblai et suite à la mise en place du remblai. La vitesse de la mise en place du remblai a été ajustée en continu, en fonction des changements de pression interstitielle observées et des tassements et déplacements latéraux mesurés. L´amélioration de la portance des sols de fondation à l´intérieur de l´enveloppe des drains de papier, et induite par la consolidation, a été confirmée par les essais au piézocône effectués neuf mois après la dernière mise en place du remblai. Les pression interstitielles et tassements mesurés ont été en accord avec les valeurs calculées lors de la conception des travaux. Cet article décrit le programme d´instrumentation géotechnique et les résultats du programme de suivi. Un autre article dans ces comptes rendus présente les résultats de l'étude géotechnique et la conception des mesures de contrôle envisagées.

1. INTRODUCTION

The twinning of Hwy 43 across the Iosegun River valley required the construction of 6 to 13 m fill heights across a 500 m stretch of very soft, deep, meltwater channel deposits that extended to 30 m in depth. In order to successfully construct the project and achieve satisfactory long-term highway and bridge performance, it was necessary to implement staged construction, deep drainage measures (strip drain, sand blanket and wicks), a stabilizing saddle berm for a high fill embankment, mechanically stabilized earth (MSE) bridge headslopes, and surcharge loading. Installation and monitoring of geotechnical instrumentation was done to: confirm design assumptions; adjust the rate of fill placement to ensure the stability of the embankment, and; measure the progress of fill settlement and foundation consolidation. This paper presents a summary of the (1) instrumentation installation, (2) as-constructed staged fill placement schedule; (3) results of the pore pressure, settlement and lateral movement monitoring; and (4) the foundation soil consolidation-induced strength gain.

The paper presents a discussion of results at selected high embankment fill areas and steep, low, bridge fill headslope where wicks were installed as well as results from an embankment fill area where wick drains were not used. Vertical slope indicators were also installed at the crest of a cut slope due to concerns about a pipeline adjacent to the cut. The results of that portion of the monitoring program are not provided in this paper.

2. INSTRUMENTATION

The geotechnical instrumentation included a total of 40 piezometers (PP), 1 vibrating wire (VW) settlement cell (SC), 13 temporary settlement plates (SP), 1 horizontal slope indicator (HSI) and 4 vertical slope indicators (VSI). Shortly after completion of the fill, 17 surface monuments or survey pins (SM) were installed at regular intervals. The layout of instrumentation is shown in Figure 1.

2.1 Installation and Objectives

The instrumentation was installed in the following sequence during construction:

The PPs, HSI and SC were installed after completion of the sand blanket, and during installation of the wick drains. The VSIs were installed after completion of the saddle berm construction. The SPs were installed after the completion of the majority of the fill in the first year of construction. The SMs were installed after the completion

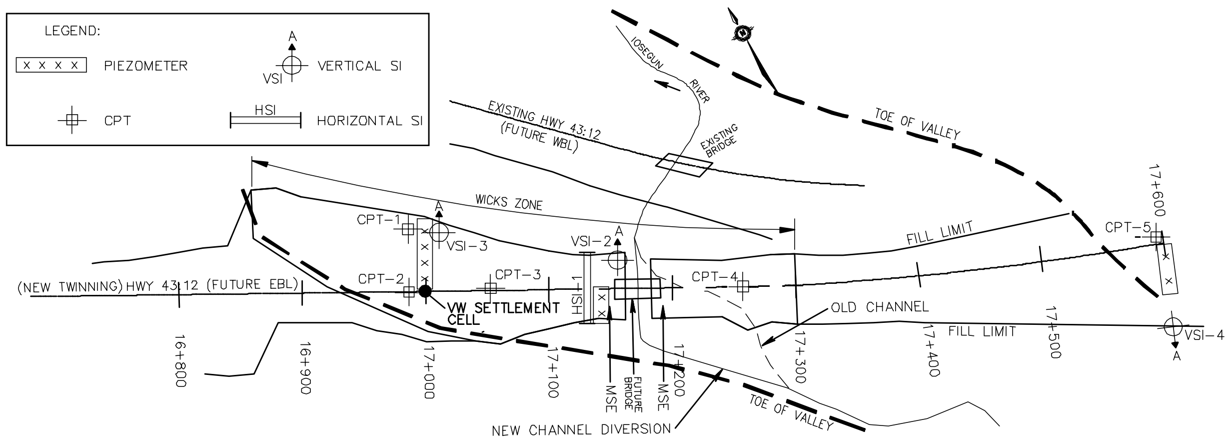

Figure 1. Layout of Instrumentations

of the surcharge fill in the second year of construction.

Pneumatic piezometers were installed at varying depths and locations along, and across, the fill footprint. During the fill placement, the monitored pore pressure data was used to regulate the rate of construction.

The settlement devices measured the elastic settlement at the top portion of the sand blanket as the fill was being placed and the subsequent consolidation with time. The HSI was used at the low fill headslope because of economy and small footprint area; the more expensive VW cell was used at the high fill where greater settlements were expected to occur.

The VSIs monitored the deformation, and by inference the stability, of the fill slopes. The SPs were installed to supplement the SC and HSI data, to “gauge” the crude settlement profile along the valley crossing and at five cross-sections perpendicular to the alignment. The settlement data was used to assist in calculation of the thickness of the surcharge fill placed during the second construction season.

The SMs consisted of rebar, installed at 20 m intervals for approximately 300 m stretch (Sta. 16+940 to 17+300). The SMs were used for long term surface monitoring.

2.2 Monitoring Frequency

All instruments were monitored regularly (daily or as required) during fill placement and intermittently after completion of fill placement. Fill placement rates were restricted to about 1 to 1.5m per week or longer durations. The slope indicators and settlement cells were monitored at weekly to monthly intervals during construction; post-construction monitoring will be at semi-annual intervals. The surface monuments will be surveyed semi-annually to annually to gauge the settlement conditions at the top of the fill. The SPs were surveyed 3 times during the 9-month interval between first and second year construction.

2.3 Improvement of Soil Strength

The effect of soil improvement from consolidation due to fill placement was investigated with CPT (May 2002) in comparison with previous (1999) results to verify the improvement in undrained soil strength (Su) achieved after a total consolidation duration of 1.5 years. The CPT holes done in 2002 were located as close as possible to those advanced in 1999.

3. MONITORING RESULTS

Different behaviors of pore pressure response were observed for the high fill area, with wick drains, and low fill area without wicks. At the fill area with wicks, significant upward hydraulic gradients were observed. This dissipation of excess pore in the shallow area was the result of effectiveness of the wicks to provide vertical drainage. At the fill area without wicks, higher pore pressures were monitored at shallower depth with decreasing pore pressure observed at increasing depths. The non-dissipation of excess pore pressure at shallow depth was due to the lack of vertical drainage without use of wicks

For the wicks areas, high pore pressure ratios (@ $\overline{B}$ =0.5 to 0.8) were observed at high fill areas whereas at the low fill area, the pore pressure generally stabilized at the top of the sand blanket. At the high fill area, approximately 3.5 m of settlement were monitored over a 1.5-year duration, for a fill height of approximately 13 m. The monitored settlement was approximately 80% of the estimated value at high fill area. At the low fill area, approximately 1.2 m of settlement was monitored over the same duration, for a fill height of approximately 6 m. The monitored settlement was approximately 50% of the estimated value at low fill area.

For the area with wicks, no major lateral movement was observed from VSI results. At the fill area of no wicks, some minor creep and lateral spreading movement of foundation soil can be observed.

3.1 High Fill Saddle Berm Area with Wicks

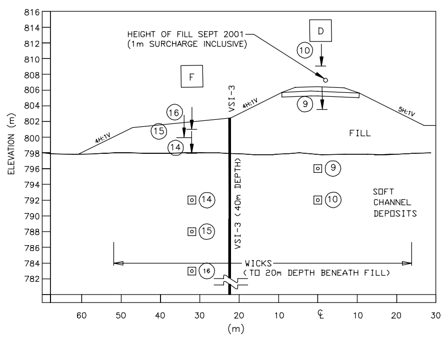

Figure 2a. Summary of Pore Pressure at High Fill with wicks (Sta. 17+000)

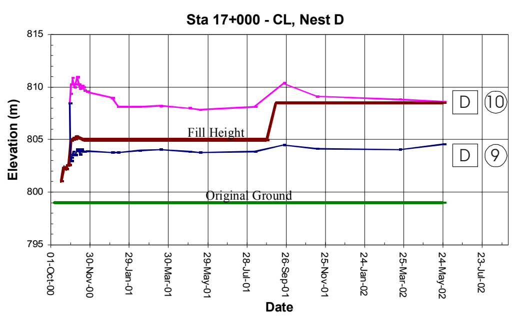

Figure 2b. Pore Pressure response vs. Fill Placement (centreline)

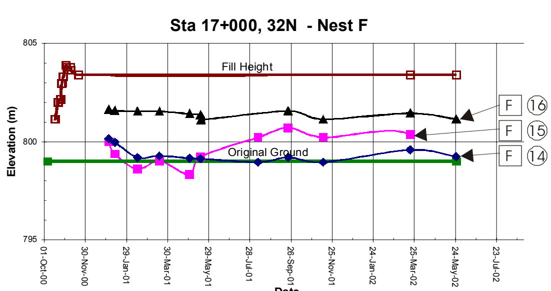

Figure 2c. Pore Pressure response vs. Fill Placement (20 m N at saddle berm)

This section presents the behaviour of pore pressure response, settlement and lateral movement for the 13 m high fill saddle berm embankment with wicks installation.

3.1.1 Pore Pressure

In Figure 2a, the summary of stabilized pore pressures are presented for various depths below the high fill embankment where wicks are installed. Pore pressure generally dissipated and stabilized to a lower value at 2 to 4 weeks after placement of a fill lift. The figure shows that higher pore pressures were present at lower elevations. The increase of excess pore pressure with depth indicates the presence of an upward vertical hydraulic flow gradient indicating the effectiveness of the wicks in dissipating excess pore pressure in the shallow area. This gradient serves to drive seepage flow upward through the wick drains where it dissipates in the sand blanket drain. Site observations confirmed that there was substantial outflow from the sand blanket.

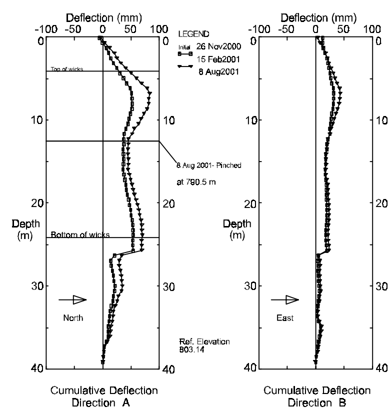

Figure 3. Lateral deflection (VSI-3) at High Fill Saddle Berm (Sta. 17+000)

Excess pore pressures in the foundation soils, $\overline{B}$, were greater in the core (@ $\overline{B}$ =0.8) than the saddle berm area (@ $\overline{B}$ =0.5) of the fill.

In Figures 2b, 2c, the pore pressure response to the fill placement is presented. Increased pore pressures were observed in response to increases in fill height. Dissipation rates were consistent with the consolidation model predictions.

3.1.2 Lateral Movement

One VSI was installed at the top of the saddle berm to 40 m depth. The monitoring results are shown on Figure 3. The location of the VSI is shown on Figure 2a.

Figure 3 shows:

- No movement in the top portion of the VSI, which may indicate that the relatively stiff saddle berm was effective in resisting lateral spreading within the fill.

- Some shear movement (40 to 50 mm) was noted at 24 to 25 m depth near the base of wick drain installation. The minor movement in this zone may be the result of improved soil strength within the zone of wick installation due to consolidation of the soft channel deposits.

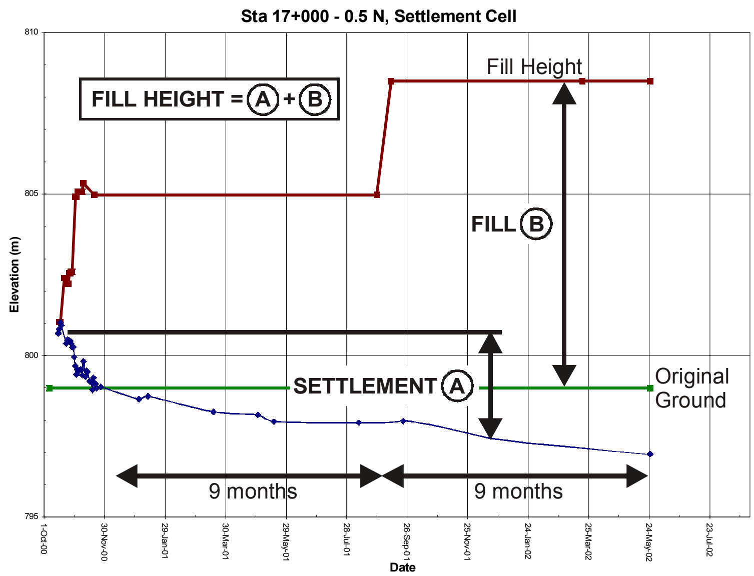

Figure 4. Settlement Response vs. Fill Placement with Wicks at High Fill Area

- Some lateral spreading (approximately 100 mm) was monitored at just below the elevation of original ground. This movement can be interpreted as outward movement of the original ground below the berm. The VSI was pinched at a 13 to 14 m depth, after a duration of 9 months. It is possible that a combination of downdrag and differential lateral spreading between different soil zones pinched off the VSI casing.

3.1.3 Settlement

The high fill settlements, as monitored by the SC are presented in Figure 4.

The settlement results show that 90 to 95% of the ultimate consolidation was achieved within a nine month period after fill placement. This is in agreement with the predicted rate of settlement.

3.2 Low Fill Area (Bridge Headslope Sta. 17+145) with Wicks

3.2.1 Pore Pressure

Piezometers were installed at varying depths within an 8m zone beneath the 6 m thick fill footprint area with wicks installation. A summary of the pore pressure response is shown on Figure 5a. The results for the piezometer nests at the centreline and toe of the fill are presented in Figure 5b.

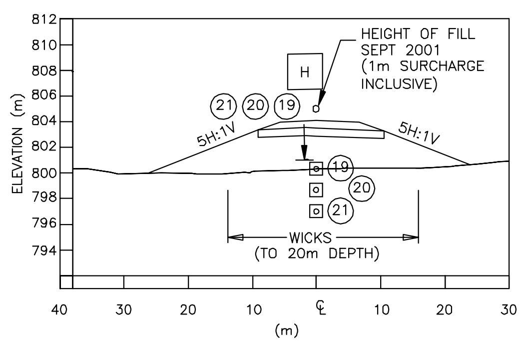

Figure 5a. Summary of Pore Pressure Response at Headslope Fill (Sta. 17+140) with wicks

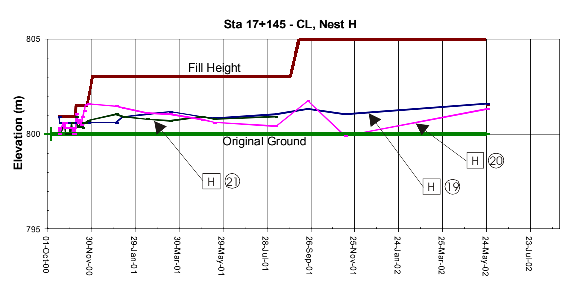

Figure 5b. Pore Pressure response vs. Fill Placement (centreline)

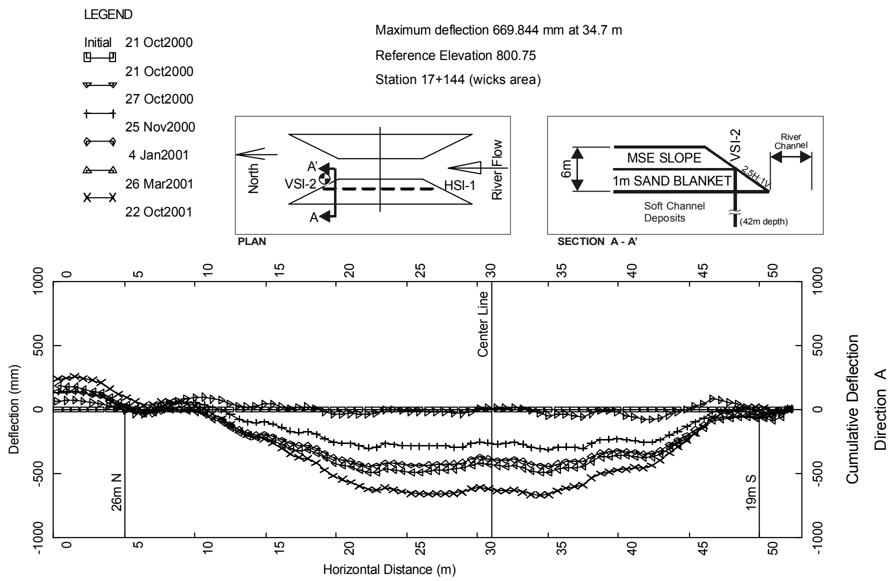

Figure 6a. Settlement Response (HIS-1) vs. Fill Placement with Wicks at MSI Headslope

The build-up of excess pore pressure was less evident in the low fill area than the high fill areas. The reduced thickness of fill (2 to 4 m) above the sand blanket, the slow rate of staged construction and the good drainage performance of the manufactured sand drainage blanket combined to limit the build-up of pore pressure. In general, the pore pressures equalized to the top of the sand blanket. A significant upward pore pressure gradient was not observed.

Based on these findings one could interpret that in areas of low fill, and hence a narrow footprint or width of fill, it may be possible to use shallower wick drains or otherwise optimize the wick drain design.

3.2.2 Lateral Movement

A VSI was installed to over 40 m depth at the northwest corner of the headslope just above the sand blanket elevation as shown in Figure 1. Figure 6b shows the lateral movements measured at this VSI. The figure shows that only minor surface movement occurred; indicative of the relative rigidity of the sand blanket and mechanically stabilized earth (MSE) bridge headslope fills.

Minor bulging of about 25 mm was measured within the depth of wick installation which is also indicative of the improved soil strength of the consolidated fill relative to the adjacent area below the river with no wicks installed.

3.2.3 Settlement

An HSI was installed within the sand blanket across the base of the west headslope at the location shown in Figure 1.

The settlement results (HSI-1) are presented in Figure 6a. Approximately 1.2 m of settlement was monitored over a one-year duration for a 4 m fill height. An additional 0.2 m of settlement was measured over a nine month duration after a 2 m surcharge fill was placed over the low fill area. A comparison of the measured settlement of low and high fill areas suggests that surcharge loading is important in achieving the 95 to 98% consolidation target. The surcharge is perhaps more important in the low fill areas.

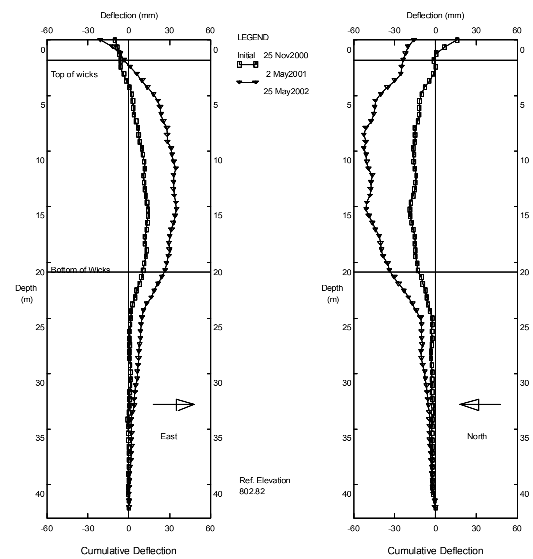

Figure 6b. Lateral Movement (VSI-2) at MSE Headslope

3.3 Fill Area Without Use of Wicks (Station 17+600 @ 8 m fill)

Wick drains were not installed in an area east of the river where better soil strengths were found. Monitoring results from this area are presented as a counterpoint to the monitoring results from wick drain areas.

3.3.1 Pore Pressure

Piezometric response results are summarized in Figure 7a. Figures 7b and 7c show the pore pressure response along the embankment centerline and at the toe area of the fill.

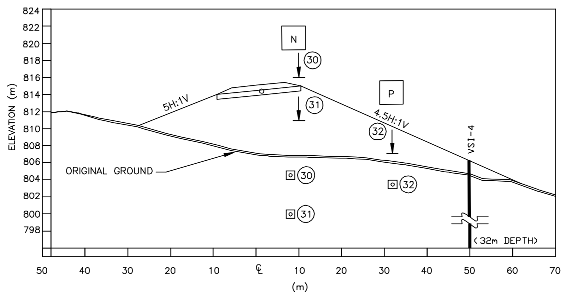

Figure 7a. Summary of Pore Pressure at Fill without wicks and VSI-4 location (Sat 17+600)

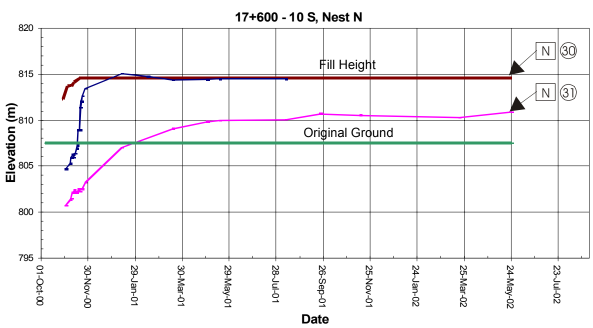

Figure 7b. Pore Pressure Response vs. Fill Placement Without Wicks (centreline)

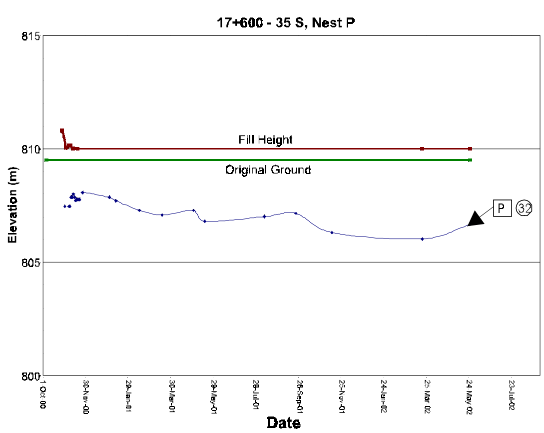

Figure 7c. Pore Pressure Response vs. Fill Placement without Wicks (toe area)

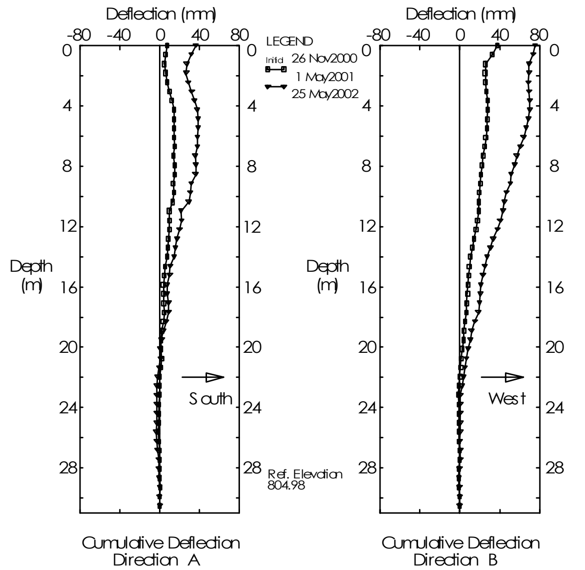

Figure 8. Lateral Movement (VSI-4) at Fill without wicks (Sta. 17+600)

A pore pressure ratio ($\overline{B}$) of 0.5 or above was determined for the center area of fill footprint. Dissipation of pore pressure was observed at the toe area of the fill while dissipation of pore pressure was not observed along the centerline of the fill. The lack of wick drains and drainage layer contribute to the lack of pore pressure dissipation.

3.3.2 Lateral Movement

Figure 7a shows the location of VSI installed at toe area of fill slope. Figure 8 shows the lateral movement measured by the VSI. Lateral spreading (over 70 mm) of fill and foundation soils was observed. Discrete shear movement was not monitored.

4. IMPROVEMENT OF SOIL STRENGTH

CPT probing (May 2002) was undertaken 1.5 years after completion of the majority of the fill, 9 months after completion of the surcharge fill, at locations of previous (1999) CPT sites. Selected comparative CPT results for the wicks area are provided in Figure 9a. The post-construction CPT result confirm that a significant increase in soil strength was achieved for the wicks area. Selected comparative CPT results are provided in Figure 9b for the area without use of wicks and significant increase in soil strength was not observed. This lack of soil improvement can be due to different soils of better strength (Su @ 50-70 kPa) in comparison with the weak soils (Su @ 20-40 kPa) at the wicks area.

At the wicks area, the observed increase in soil shear strength is in close agreement with the prediction based on Skempton's relationship between undrained shear strength with respect to overburden pressure and plasticity index.

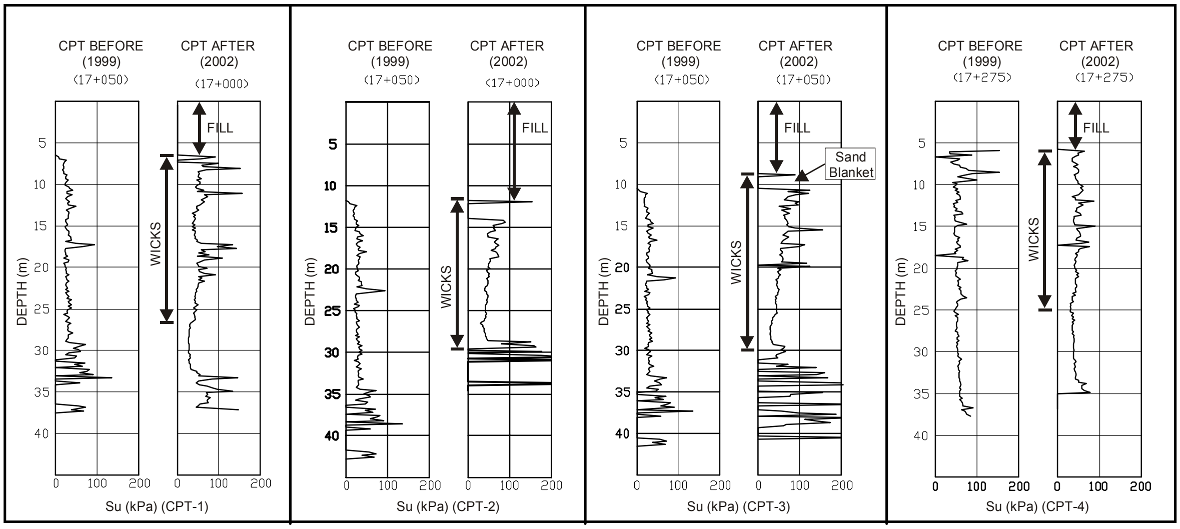

Figure 9. CPT Strength Improvement at Areas with Wicks

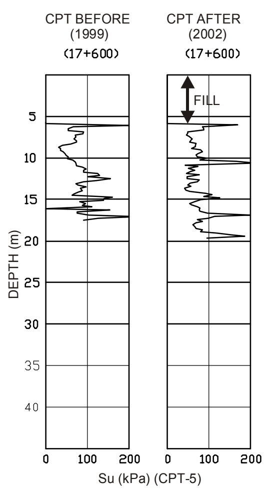

Figure 9b. Comparative CPT Results at Area without Wicks

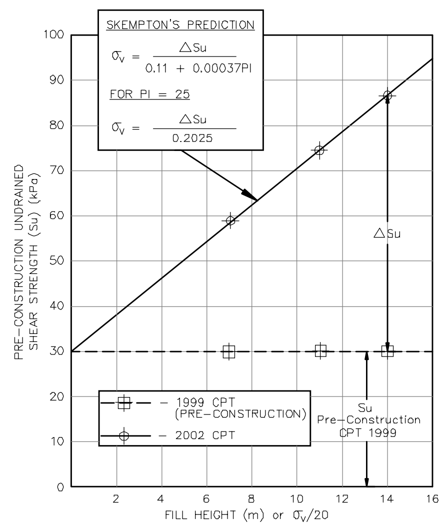

Figure 10. Plot of Su vs. Fill Height (Skempton's Prediction vs. CPT Data)

Generally for soft clay channel deposits with a plasticity index (PI) of 25% , an increase of Su ranging from 25 kPa to 55 kPa can be achieved from 6 to 14m of surcharge fill.

Figure 10 clearly shows that the CPT test results correlate well to the predicted strength gain based on Skempton's equation.

The strength gain iranged from 20 to 60 kPa for soils with initial shear strengths of 25 to 50 kPa.

5. CONCLUSIONS

- The wick drain, lateral drain and sand blanket system performed as designed and dissipated pore pressure in close agreement with the predicted drain performance.
- Greater excess pore pressures were generated below high fills, and along the centerline or greatest thickness of fill, relative to low fills and saddle berm or toe of the fills.
- Significant drainage flow was observed, requiring the installation of geotextile blanket and riprap protection to control piping conditions. Future design should consider piping from outflow at edge of sand blanket and provide for a toe filter protection.
- The estimated settlement (3.3 m for 11 m fill) is approximately 70 to 80% of the monitored settlement (3.5 m for 13 m fill).
- After a 1.5-year total consolidation duration, the

beneficial effect of consolidation on shear strength gain was found to be in agreement with Skempton's prediction relating to plasticity index (PI) and overburden pressure (σ_v).
- CPT is an appropriate tool for assessing improvement in soil strength resulting from consolidation.
- The use of a surcharge fill is critical at low fill areas to provide pre-consolidation effect and reduce future settlements.
- The mechanically reinforced earth slope and a high strength, coarse sand blanket produce a rigid soil mass that limits lateral spreading of the bridge headslope area.
- For settlement monitoring,
  - The use of SC was very successful and provided what were believed to be accurate and precise settlement measurements. No maintenance cost were incurred, however the SC has a higher cost (approximately $5,000CAN) relative to SP.
  - The use of HSI required substantial maintenance costs due to siltation and icing of the pipe (due to persistent moisture in the sand blanket and river flooding of the pipe ends).. Flushing of accumulated silt from the HSI pipe was required. Icing up of the pipe prevented reading in winter months.
  - The use of low cost settlement plates was successful only during the consolidation period (no construction activity). At resumption of fill placement, the vertical rod of the settlement plate generally moved laterally with the fill and was rendered defunct. For long term settlement monitoring the use of vibrating wire SC are recommended.
- Pneumatic piezometers for the project had a success rate of about 75%. Failure of some PP's was attributed to excessive stretching of the cables and compressive pinching-off.

6. ACKOWLEDGEMENTS

The authors would like to acknowledge the assistance of Chris Gräpel, Randy McGilvray and Bob Patrick of EBA, and Alberta Transportation for their support throughout this project.

7. REFERENCE

Skempton, A.W. and Bjerrum, L. 1957, A contribution to the settlement analysis of foundations on clay. Geotechnique, 7: 168-1