Highway embankment performance on compressible clay at Highway 1/ 200th Street, Langley, British Columbia

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ABSTRACT The Highway 1 / 200th Street area in Langley, British Columbia is underlain by some of the softest and most compressible clays in the Lower Mainland of British Columbia. Geologically, the clay was deposited in marine environment following retreat of the Vashon ice sheet from this region some 13,000 years ago. Extensive field and laboratory tests have illustrated the sensitive and highly compressible nature of the clay deposit in this area. The data also indicated that the clay at 200th Street is even more compressible than other deep clay deposits in Langley and Surrey. Highway developments at 200th Street over the last 50 years have met significant challenges, particularly embankment settlements adjacent to piled grade separation structures. This paper describes the properties of the clay at Highway 1 / 200th Street, compares these properties to those of other clays nearby, and presents the settlement performance of the highway embankments at Highway 1/ 200th Street, including the original 200th Street overpass built in the 1960s that has since been demolished, and the new replacement interchange that was completed in 2004. Lessons learned from highway developments on this highly compressible clay deposit are described.

Introduction

The Surrey-Langley area in British Columbia, is covered by extensive deposits of Capilano Sediments, which are glaciomarine and marine sediments deposited following retreat of the Vashon ice sheet from this region (GSC Map1484A). The Capilano Sediments are mostly soft clays deposited in marine environment, between 10,000 and 13,000 years ago, when the sea was 15 m or more above present sea level. These clays have not been overridden by ice. Extensive field and laboratory tests have illustrated the sensitive and highly compressible nature of these clays, including those at Highway 1/ 200th Street interchange. The data also indicated that the clay at 200th Street is even more compressible than other deep clay deposits in Langley and Surrey. Highway developments at 200th Street over the last 50 years have met significant challenges, particularly embankment settlements adjacent to piled grade separation structures. This paper describes the compressibility properties of the clay at Highway 1 / 200th Street, compares these properties to those of other clays at nearby bridge sites, and presents the settlement performance of the highway embankments at Highway 1/ 200th Street, including the original 200th Street overpass built in the 1960s that has since been demolished, and the new replacement interchange that was completed in 2004. Lessons learned from highway developments on this highly compressible clay deposit are also described.

Highway 1/ 200th Street Site Conditions

The current 200th Street interchange is a replacement structure located at the intersection of 200th Street and Trans-Canada Highway (#1) in the northwest corner of the Township of Langley (Figure 1). The clay properties at Highway 1/ 200th Street are well described by Zergoun et al. (2004), which presented the performance of an instrumented test fill that was constructed as part of the new replacement interchange. Figure 2 (from Zergoun et al. 2004) shows a cone penetration test and soil profile at the south approach. The original ground was underlain by 1 m of weathered clay crust and 22 m of soft silty clay, with occasional thin sand lenses, overlying dense till-like soil. The silty clay is medium to low plastic with plasticity index ranging from 20 to 50%, and natural water content ranging from 52 to 88%, close to or higher than the liquid limit. Zergoun et al (2004) also described the results of constant rate of strain oedometer tests on this clay that suggested preconsolidation pressures (p'_c) constant at about 95 kPa from 2 to 6 m depth, then reducing with depth to equal the effective overburden pressure (p'_o) at about 12 m, as illustrated in Figure 2. The constant rate of strain test results shown in Figure 3 (from Zergoun et al. 2004) illustrate the highly compressible characteristic of this clay.

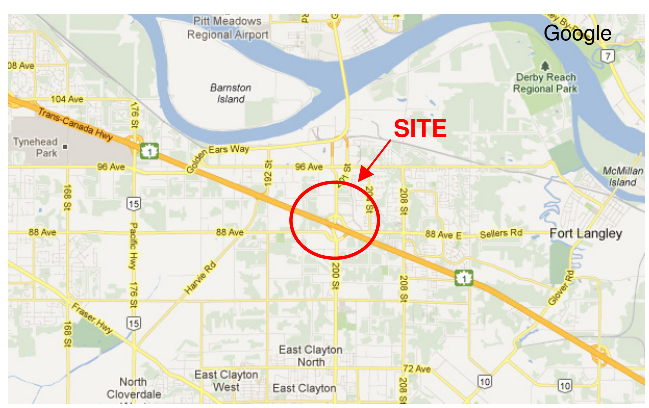

Fig. 1. Location of Highway 1/ 200th Street Interchange in Langley, BC

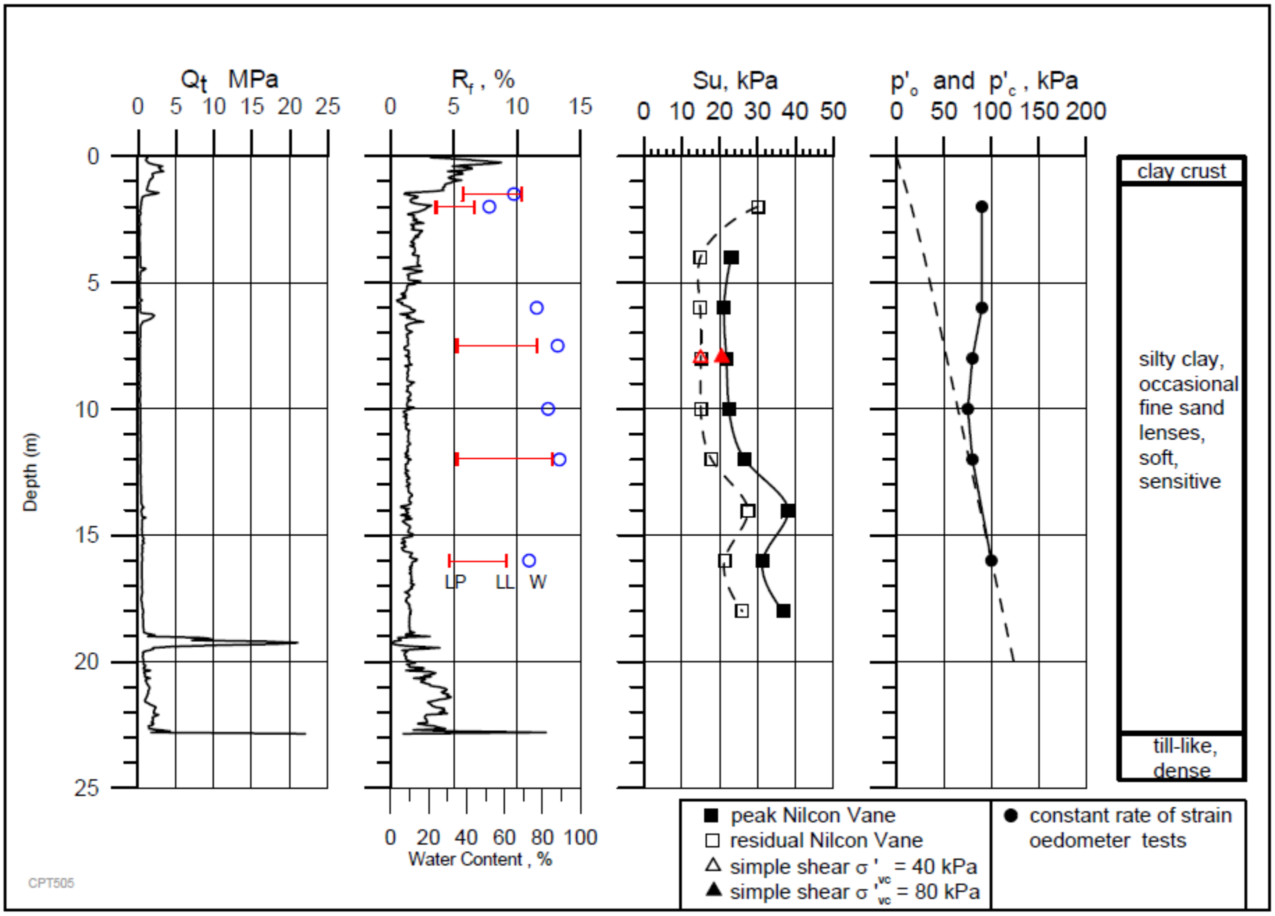

Fig. 2. Cone penetration test and soil profile at Highway 1/ 200th Street site (from Zergoun et al. 2004)

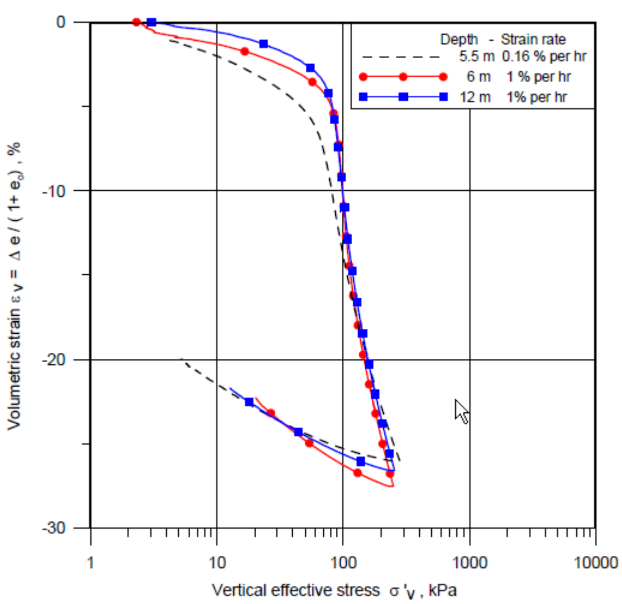

Fig. 3. Constant rate of strain consolidation test results at 200th Street site (from Zergoun et al. 2004)

Extensive test holes in this area from various subsoil investigations over the years indicate that the clay profile at the north approach has more and thicker interlayers (or pockets) of sand, compared to the clay at the south approach. This is illustrated in Figure 4 which shows a typical cone penetration test (CPT) profile at the north approach and one at the south approach. The groundwater table was generally within 1 m of ground surface. Typical ranges of clay properties from laboratory tests at the north and south approaches are summarized in Table 1. Other than the presence of sand layers, the clay properties at the north and south approach areas are not significantly different. Note the high laboratory compression index of the clay at 200th Street, with values up to 3.3.

Table 1 Typical Clay Properties at Highway 1/ 200th Street

Property	North Approach	South Approach
Water Content, WC (%)	34 to 85	71 to 93
Liquid Limit, LL (%)	32 to 81	49 to 70
Plasticity Index, PI (%)	15 to 51	22 to 34
Initial Void Ratio, e_o	1.7 to 2.6	2.0 to 2.7
Compression Index, C_c	1.6 to 3.3	0.7 to 2.2

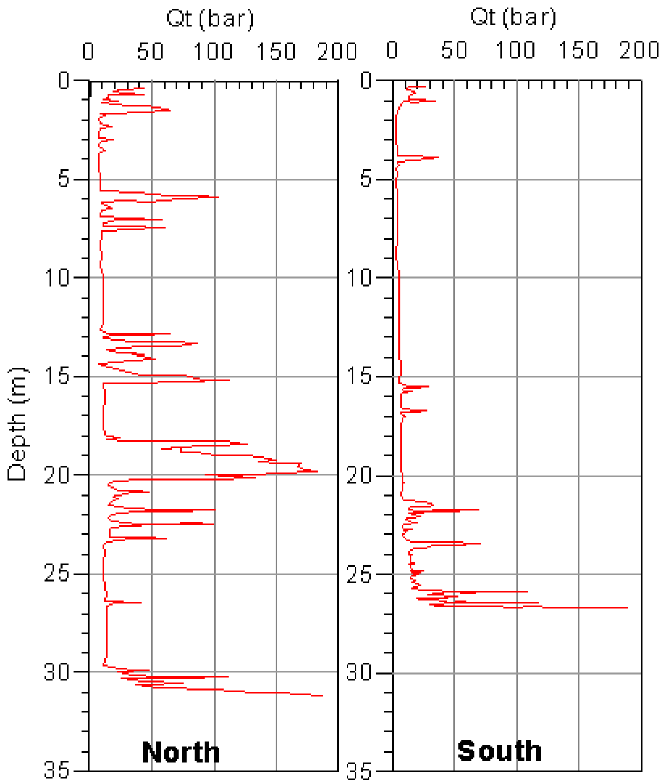

Fig. 4. Cone penetration test profiles at north and south abutments at 200th Street site

Comparison with Other Sites

Relevant properties of the Capilano Sediments published in the literature for three other bridge sites in Surrey and Langley are described below. The site locations are marked on the geological map in Figure 5.

Colebrook Overpass, Surrey

Crawford and DeBoer (1987) presented properties of the clay at the King George Highway (99A) overpass that spans Colebrook Road and the CP railway in Surrey, as well as a 15-year settlement performance record of the approach embankments. They performed laboratory consolidation tests on the clay and compared the laboratory results with field observations. They indicated that an accurate value for preconsolidation pressure could not be obtained from laboratory results, but that their settlement monitoring suggested that about 15-20 kPa can be applied to the clay without consolidation settlement. The clay at Colebrook overpass is described as very soft silty clay of low plasticity, with occasional layers of sea shells, and is up to about 40 m thick, underlain by very dense till-like silty gravel deposits. Typical properties of the clay derived from laboratory tests are summarized below:

Water Content	36 to 49%
Liquid Limit	27 to 38%
Plasticity Index	Average 11%
Initial Void Ratio	1.25
Compression Index	0.27 to 0.67

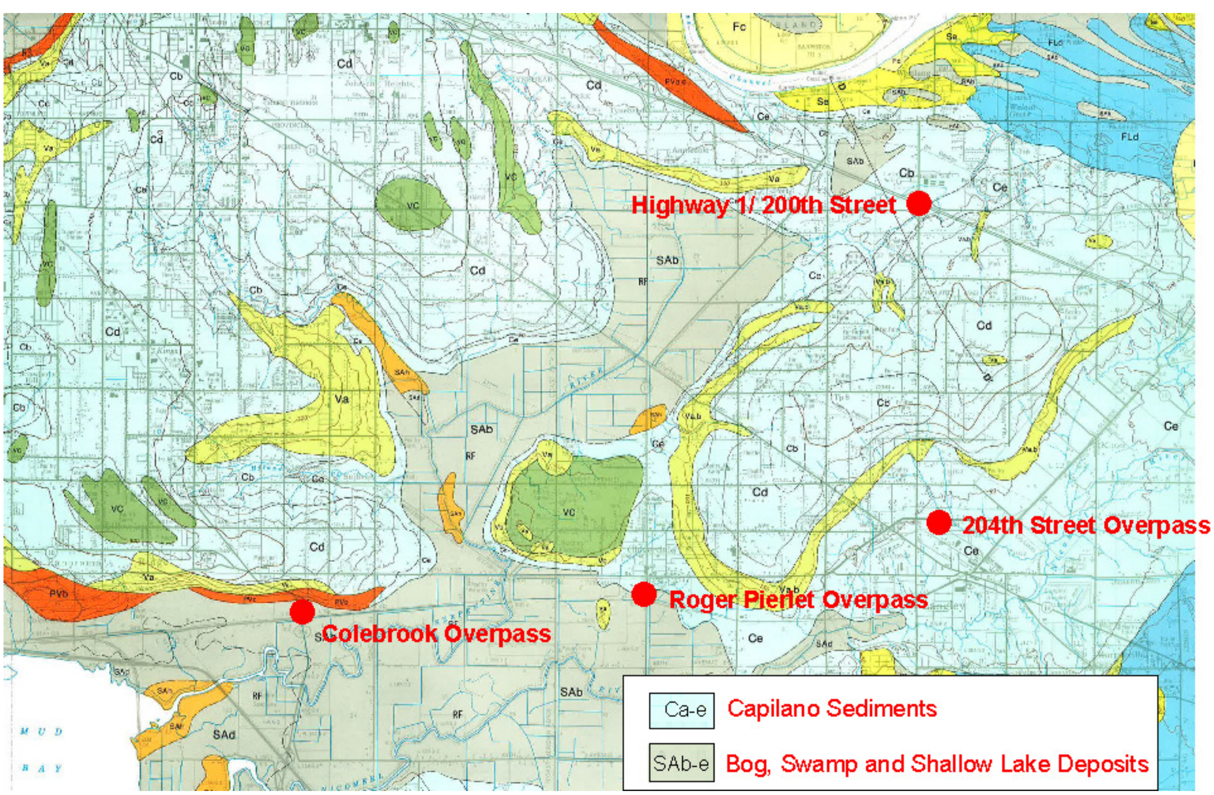

Fig. 5. Surficial geology map showing site locations in Surrey and Langley, BC (from GSC Map 1484A)

Roger Pierlet Overpass, Cloverdale

Yang and Gohl (2006) described the design of the new Roger Pierlet bridge that was constructed on Highway 15 over the CP railway in Cloverdale, Surrey. The new overpass was completed in 2006 to twin the existing Roger Pierlet overpass, as part of the Highway 15 Border Infrastructure Program. The site is underlain by low to medium plastic silty clay, up to 50 m deep, overlying dense till-like deposits of sand, gravel, silt and clay. Yang and Gohl highlighted the sensitive and compressible nature of the soft clay at this site. The high sensitivity of the clay is due to freshwater infiltration that caused leaching of the saline pore fluid following uplift of the clay above sea level during glacial retreat. Based on a review of settlement records of the existing approach embankments, Yang and Gohl suggested that there is a load threshold beyond which settlement increases sharply, and that this threshold is judged to be 30 to 40 kPa. Accordingly, their design of the new overpass was based on keeping approach fill loading to less than 30 kPa. Further descriptions of the clay are included in Sy et al (2011), which described retrofit of the old Roger Pierlet overpass that was displaced and damaged in November 2004 by foundation soil movement caused by failure of a large soil stockpile placed adjacent to the bridge. Typical properties of the clay at Roger Pierlet are summarized below:

Water Content	30 to 60%
Liquid Limit	30 to 55%
Plasticity Index	10 to 30%
Initial Void Ratio	1.5 to 1.7
Compression Index	0.8 to 0.85

204th Street Overpass, City of Langley

Sully and Parra (2008) and Bui et al (2011) presented properties of the clay at the new 204th Street overpass that spans Langley Bypass (Highway 10) in the City of Langley, British Columbia. The new overpass was completed in 2007. The clay was described as soft silty clay to clay, becoming firm to stiff with depth, and underlain by very dense clayey gravel at a depth of about 85 m at the north approach and more than 100m at the south approach. The typical clay properties at 204th Street are summarized below.

Water Content	40 to 45%
Liquid Limit	48 to 72%
Plasticity Index	26 to 44%
Initial Void Ratio	1.1 to 1.2
Compression Index	0.4 to 0.56

Comparison of Clay Compressibility

The laboratory compression index (C_c) values of the clays at the four sites discussed above are summarized in Table 2. Table 2 illustrates that although these clays were all deposited in marine environment shortly following end of glaciation, their compressibility characteristics are very different at the four sites. The silty clay at Highway 1/ 200th Street is the most compressible of the clays compiled in Table 2.

Table 2 Summary of Compression Indices at 4 Clay Sites in Langley and Surrey

Site	Compression Index
Highway 1/ 200th St Interchange	0.7 to 3.3
Colebrook Overpass	0.27 to 0.67
Roger Pierlet Overpass	0.8 to 0.85
204th Street Overpass	0.4 to 0.56

Old 200th Street Embankment Performance

The previous 200th Street bridge over Highway 1, constructed around 1964 and since demolished in 2004, was a two-lane bridge supported on seven piers that were founded on steel H-piles. The bridge ends were supported at grade on 5 m high approach fills. Highway 1 consisted of two lanes in each direction divided by a median about 40 m wide. A 1999 air photograph of the old interchange is shown in Figure 6.

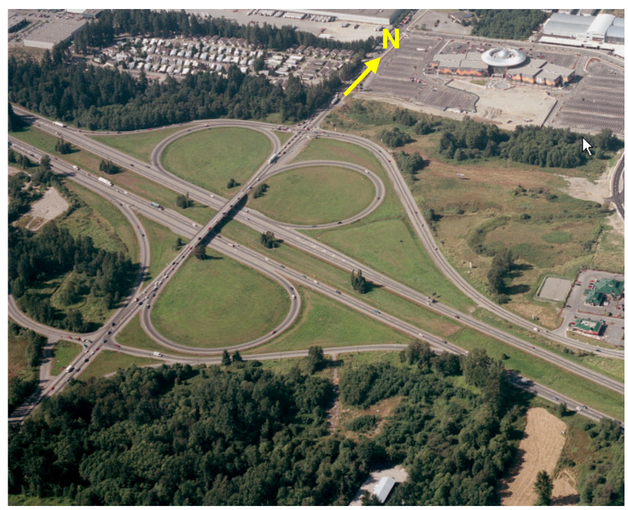

Fig. 6. Air photo of previous 200th Street Interchange in 1999

The former bridge abutments experienced considerable settlements since construction and required jacking several times over the life of the structure. Based on jacking records and survey data from BC Ministry of Transportation and Infrastructure, the approximate cumulative post-construction settlement versus time plots of the north and south abutments are shown in Figure 7. These graphs show the highly compressible nature of the silty clay at this site and the long duration of settlement. Note the much larger total recorded settlement at the south abutment, i.e. 1700 mm from 1964 to 1999, compared to the north abutment, i.e. 770 mm over the same 35-year period. This difference is due to the presence of numerous thick sand layers within the clay deposit at the north side of the bridge, and the general absence of such thick sand layers in the clay at the south side. The sand layers are likely beach deposits formed during periods of glacial melting. Figure 8 is a photograph of the excavated south embankment illustrating the settlement that has occurred during the last 40 years.

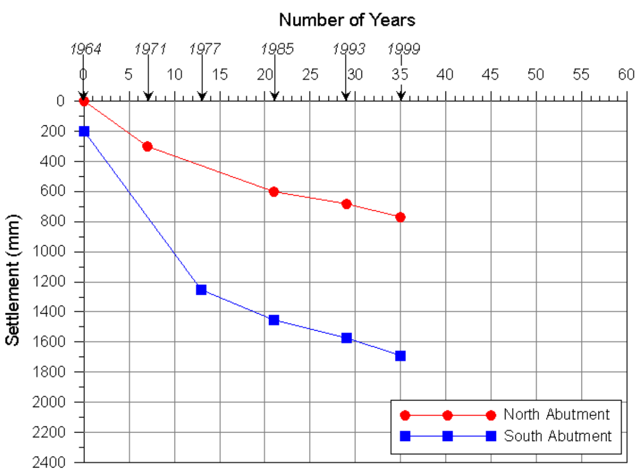

Fig. 7. Abutment settlements at previous 200th Street interchange from 1964 to 1999

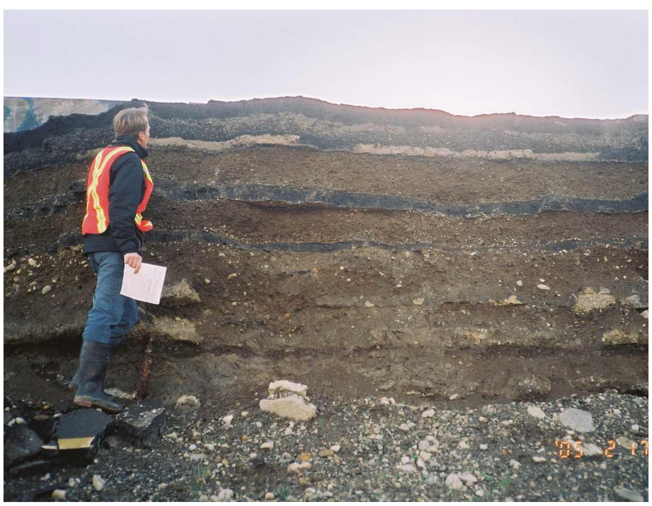

Fig. 8. Photograph of excavated south embankment of former Highway 1/ 200th Street overpass

New 200th Street Embankment Performance

The new 200th Street interchange is a six-lane north-south overpass over Highway 1. The new single-point interchange was completed in 2004. An air photograph taken shortly after construction in 2004 is shown in Figure 9. The new interchange is located 65 m west of the old interchange structure that was demolished shortly after completion of the new interchange. Highway 1 was realigned, such that the new eastbound lanes were moved north of the previous eastbound lanes, into the previous median, but the westbound lanes were unchanged.

Fig. 9. Air photo of new 200th Street Interchange in 2004

Prior to construction of the new interchange, an instrumented test fill was carried out at the proposed south approach area, as documented in Zergoun et al. (2004). The test fill was started in December 1999 and compacted sand was placed in three 1 m increments at one month intervals. The final test fill configuration was 32 m by 16 m in plan measured at the crest, 3 m high, with side slopes of 2.5H to 1V. The test fill was instrumented with surface and deep settlement gauges, piezometers and inclinometers. Figure 10 (from Zergoun et al. 2004) shows the applied fill load and measured settlements with time at several settlement gauges in the clay below the test fill. There was negligible settlement under the initial 1 m lift for one month, but under the 36 kPa loading (2 m high fill), settlement increased to 70 mm in one month, and finally, under the 54 kPa loading (3 m high fill), settlement increased significantly to 220 mm in one month. The maximum recorded settlement under the centre of the test fill from December 1999 to April 2002 (i.e. after 850 days) was 740 mm, and settlement was continuing. This test fill performance confirms the high compressibility and long term settlement behavior of the clay at 200th Street.

The new 200th Street interchange includes a two span piled bridge structure, and approach fills for 200th Street and Highway 1 east-bound and west-bound off ramps. The bridge is 39 m wide at the north abutment and 46 m wide at the south abutment. The pile-supported abutment walls are 7 m high, with approach slabs extending 6 m beyond the bridge abutments. The approach fill embankments are up to 6.5 m high and about 70 m wide near the maximum height. To minimize loading and hence long-term settlement, the approach fill design employed a combination of expanded polystyrene (EPS), hog fuel (wood waste), and mineral fill. The hog fuel was completely encapsulated in polyethylene sheeting. Figure 11 shows a cross-section of the embankment at the south approach, which utilized EPS, hog fuel and granular fill.

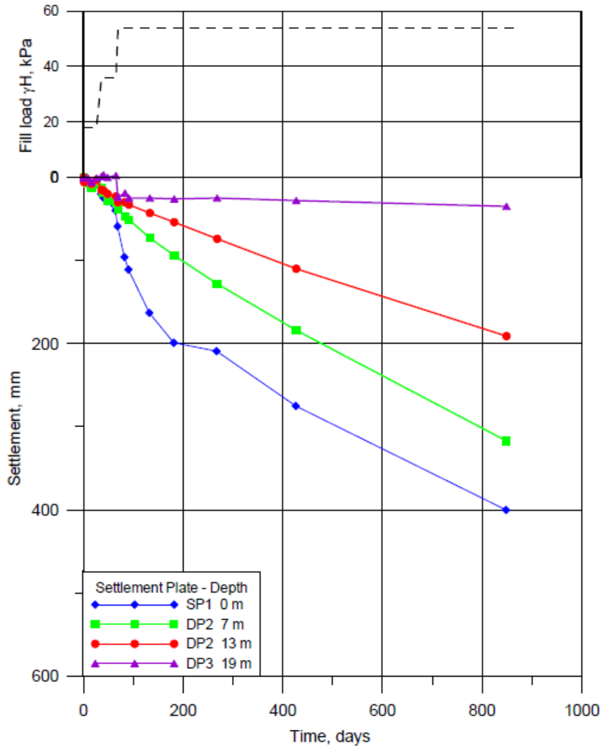

Fig. 10. Test fill load and settlement as function of time at 200th Street (from Zergoun et al. 2004)

Shortly after construction, more settlements than anticipated were occurring. Subsequent investigations revealed that old highway ditches under the new embankment had been in-filled with granular fill, and more granular fill was placed in the embankment than in the design section. Figure 12 shows the estimated embankment fill loading profile (from results of post-construction site investigation), and measured post-paving (post-construction) road surface settlement along the south approach, from June 2004 to February 2007. As shown, fill loadings were up to 110 kPa, and post-paving settlements were up to 835 mm, with the maximum settlement generally occurring where the fill loading was highest. The differential settlements caused a distinct dip of the road surface. Figure 13 shows the time rate of settlement of the monitoring point that recorded the maximum settlement at about 25 m distance south of the piled south abutment. The settlement data were measured from January 2004, about halfway into fill placement, to August 2007. The total measured settlement was 1600 mm, and the extrapolated settlement to 25 years was 2300 mm.

The differential settlement issue necessitated repair to the south approach embankment to reduce load, by replacing some of the existing shallow mineral fill with EPS. The existing approach slabs extending 6 m out from the south abutment were lifted back up to design elevation by injecting polyurethane through the concrete slabs and backfilling the voids beneath the slabs and behind the abutment wall with lightweight polyurethane. This remediation was completed in July 2008 during three weekend road closures. However, in late 2010, the 200th Street northbound concrete approach slab cracked near the abutment support. Subsequent investigation revealed there were significant gaps, or air voids, under the slabs, despite the polyurethane backfill in 2008. The northbound and southbound approach slabs were replaced in 2011.

Despite the remediations, the long-term integrity of the lightweight approach fill system (i.e. EPS and hog fuel) under such large differential settlements is uncertain.

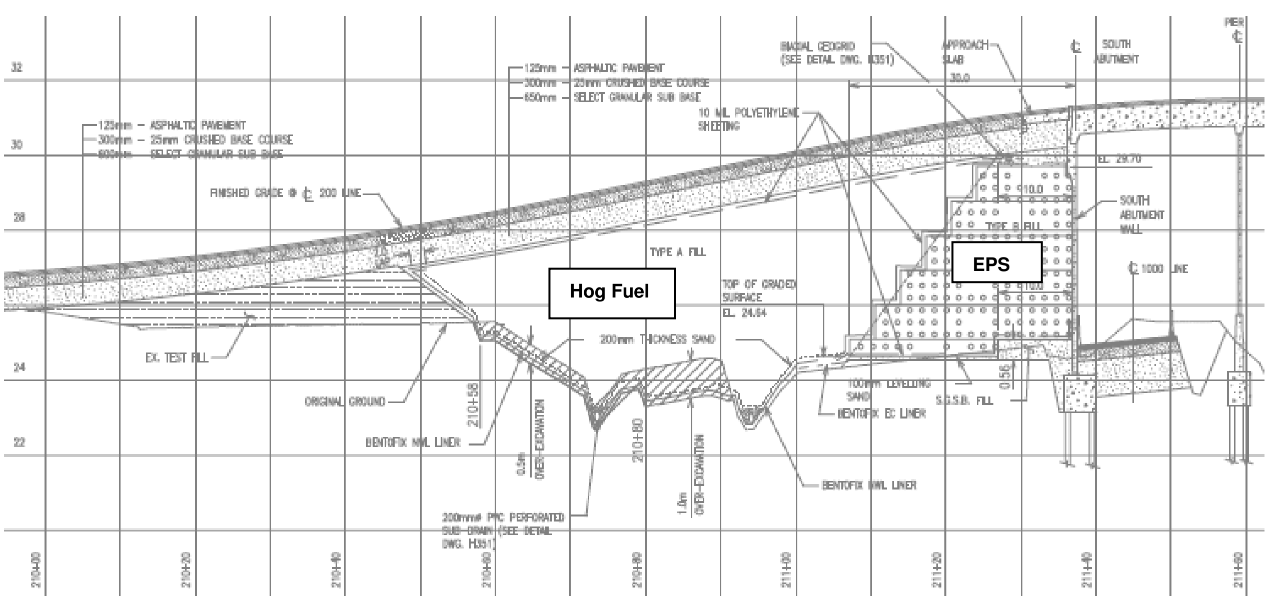

Fig. 11. South approach embankment cross-section at new 200th Street interchange

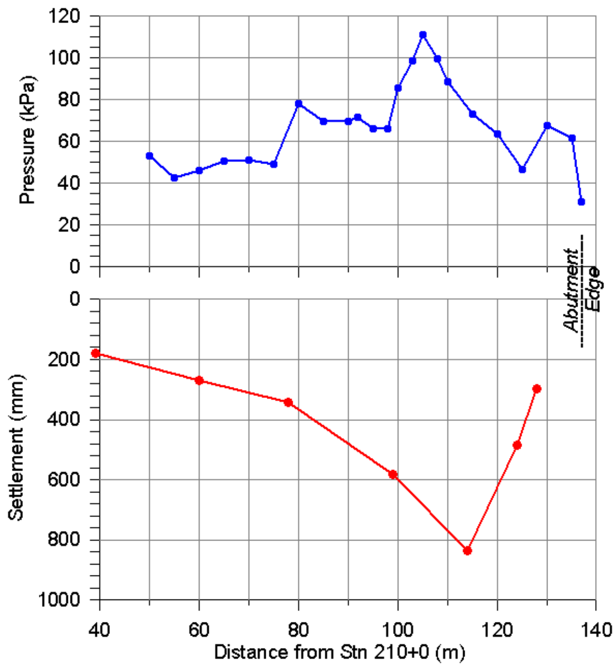

Fig. 12. Fill loading and settlement profiles at south approach embankment of new 200th Street interchange

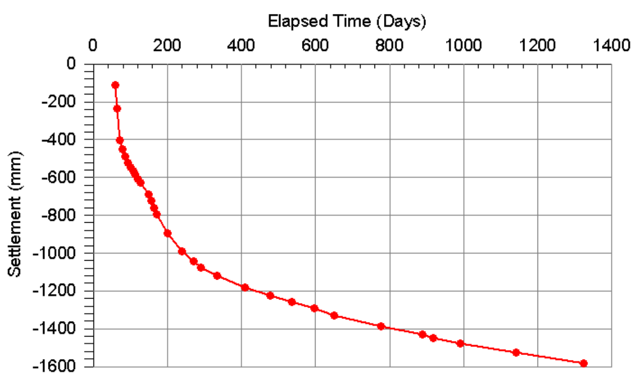

Fig. 13. Settlement vs. time for a monitoring point 25 m south of south abutment of new 200th Street interchange

Another issue discovered shortly after construction was that significant water was found in the encapsulated hog fuel system at the south approach. The presence of the water in the hog fuel increased the applied embankment fill loading, relative to design, and likely exacerbated the settlement. In addition, fluctuating water levels and introduction of oxygen into the encapsulated hog fuel system will increase the rate of decay and deterioration of the woodwaste, also resulting in increased settlement of the pavement. No practical solution was found for this issue, other than to periodically pump out the water to minimize leachate into the nearby stream.

Summary and Conclusions

The soft clays of the Capilano Sediments in Surrey and Langley, except for the top few meters of crust, are normally consolidated to lightly over-consolidated. The clays are highly compressible, but their compression index is different at the four bridge sites discussed in this paper. The clay at Highway 1/ 200th Street is the most compressible of the four clays reviewed. The preconsolidation pressure of the clay is difficult to measure reliably, but field performance data published by various authors suggest that up to about 1 to 2 m of fill loading on this clay would result in little settlement. Beyond this threshold load, settlement becomes significant.

This paper illustrates the high compressibility of the clay at Highway 1/ 200th Street area, and the importance of paying attention to design details for highway development on such compressible clay. It is critically important to monitor the actual fill loads placed during embankment construction, including any old existing fill or fill required to infill existing ditches. The actual load profile can provide indications of future anticipated differential settlements. This paper also illustrates that post-construction remediation is difficult and may not re-establish the long-term design performance of the road embankments.

References

Bui, Y.T., Sully, J.P., Parra, E.J. and Sully, T. 2011. A design approach for piles in Langley clay based on testing. 2011 Pan-Am CGS Geotechnical Conference, Toronto, Ontario.

Crawford, C.B. and DeBoer, L.J. 1987. Field observations of soft clay consolidation in the Fraser Lowland. *Canadian Geotechnical Journal*, 24: 308-317.

GSC Map 1484A. Surficial Geology. New Westminster. Published by Geological Survey of Canada.

Sully, J.P. and Parra E.J. 2008. PDA testing to evaluate axial setup in cohesive soils. *The 8th International Conference on the Application of Stress Wave Theory to Piles*, Science Technology and Practice. Lisbon, Portugal. Pp. 125-129.

Sy, A., Thavaraj, T., Hamersley, B. and Gillespie, D. 2011. Retrofit of a pile-supported bridge in soft clay damaged by failure of adjacent soil stockpile. 2011 Pan-Am CGS Geotechnical Conference, Toronto, Ontario.

Yang D. and Gohl, B. 2006. Geotechnical and seismic design of innovative Roger Pierlet bridge and approach structures. *Soil and Rock Behavior Modeling*. ASCE Geotechnical Special Publication No. 150: 458-465.

Zergoun, M., O'Brien J.A. and Broomhead, D. 2004. TransCanada Highway – 200th Street Langley Interchange, British Columbia, Canada – Part 1: test fill observations. 57th Canadian Geotechnical Conference, Quebec.