Freeze/Thaw Investigation for Rammed Aggregate Pier Elements

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ABSTRACT: In this study, Rammed Aggregate Pier® elements (piers) were subjected to freezing and thawing cycles within the top portions of the piers to study the potential for thaw softening. The piers were instrumented with arrays of temperature sensors. Some of the test piers were exposed to freezing weather conditions while others were covered with up to 1.3 m of granular fill. The field investigation was conducted in Mississauga, Canada during the period January 10 through May 7, 2008. Several piers were tested before and after the monitoring period using in-situ testing methods to evaluate strength and stiffness of the piers and the impact of the granular fill cover.

Background

Rammed Aggregate Pier® patented technology is an intermediate foundation system developed by Geopier Foundation Company Inc. and is used as an alternative soil reinforcing technology. Typical pier elements are built at 0.76 m (30 in) in diameter, up to 10 m (33 ft) in length and able to provide a 2-5 times increase in load bearing capacity comparing to unreinforced matrix soil.

The process of ramming aggregate in soil cavity in even sized lifts results in buildup of in-situ lateral confinement between matrix soil and pier aggregate. The process of pier construction is outlined in Figure 1.

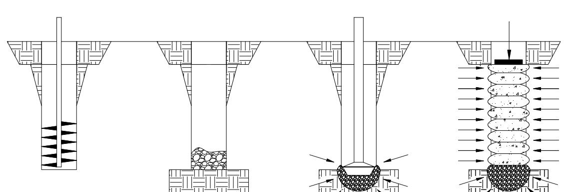

Figure 1. Simplified pier installation process

The soil profile reinforced by the piers is typically divided into upper and lower zones, where the upper zone is limited to the length of the pier and lower zone is below the pier to the desired depth of interest.

The ultimate bearing capacity of the piers within the upper zone is dependent on the aggregate friction angle and confinement provided by the matrix soil. Long piers (> 3 m) tend to deform by bulging within depth of approximately four times the diameter of the pier from the top. For short piers (< 3 m) resistance of the pier at the tip may be the limiting factor for design.

A typical 0.76 m (30 in) diameter, 3.7 m (12 ft) long pier is typically able to withhold 250 to 500 kN (50 to 100 kip) load at a settlement of 13 mm (0.5 in).

This pier system has found application in highly compressible cohesive soils with high moisture content, organic soils and unknown fill deposits. Common applications include soil reinforcement to support shallow foundations, mechanically stabilized earth wall foundations, embankment support, large storage tank support, and slope reinforcement.

Problem Statement

Winter construction of the piers in northern climates creates some challenges due to the potential impact of freeze/thaw cycles within the tops of exposed piers and within the surrounding matrix soil. Because of the need to expedite the construction schedule, construction over the winter months is necessary for many projects.

Typically, piers and matrix soil are covered with concrete foundations or floor slabs soon after construction and freeze/thaw potential is minimal; however, in some cases the construction schedule and construction sequence may result in piers being exposed to freeze/thaw conditions over the winter/spring months. Research was needed to investigate this scenario.

The research plan for investigating mitigation potential for freeze/thaw damage was implemented by providing a spoil or granular fill cover to tops of exposed piers as insulating protection. Use of a chemical stabilizer in the tops of the piers was also considered but not implemented at this phase of the research. To evaluate the impact of cover material in terms of freeze/thaw mitigation at tops of piers, temperature sensors were installed and monitored at a site in Mississauga, Canada, after pier installation in the winter for a period of four months through spring thaw. Pier stiffness was also measured at the beginning and the end of the monitoring period.

Research Objectives

The primary objectives of this research were to: (1) document pier temperature profiles for several piers constructed side-by-side with different thicknesses of granular cover material; and (2) document changes in pier stiffness following spring thaw for the reference piers.

Materials

The material used for pier construction was described as well-graded crusher run. The matrix soil moisture contents varied from 12 to 25 percent based on measurements from January and were noted as soft and saturated in the month of May. Water was observed at the surface in May. The 0.76 m (30 in) diameter piers were constructed in ten compacted lifts, each lift being about 0.3 m (1 ft) in thickness.
Granular material ("Type A") was used as cover fill and placed 0.3, 0.6, 0.9, 1.2 m thick (0, 1, 2, 3, and 4 ft) for pier numbers T1 through T5, respectively. Pier numbers 213, 278, and 279 were not specifically targeted for variable cover fill and were left exposed.

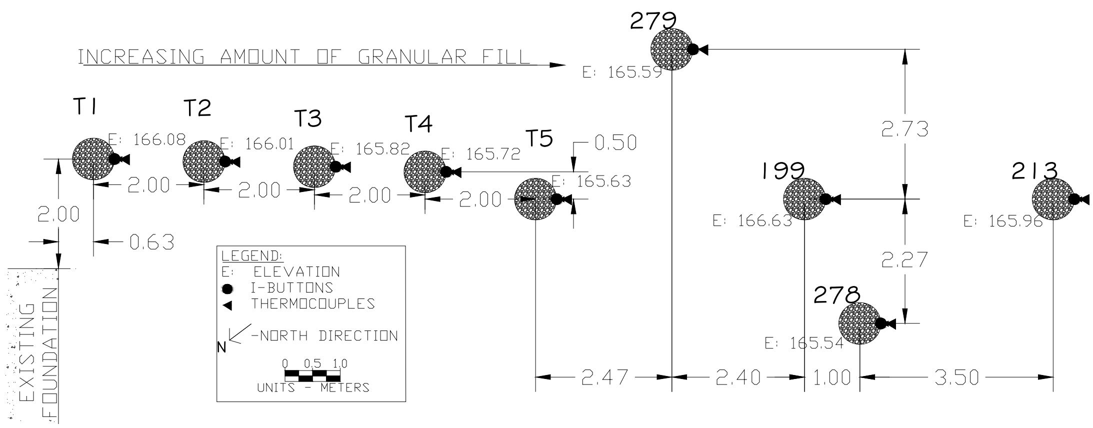

Figure 2. Pier plan layout

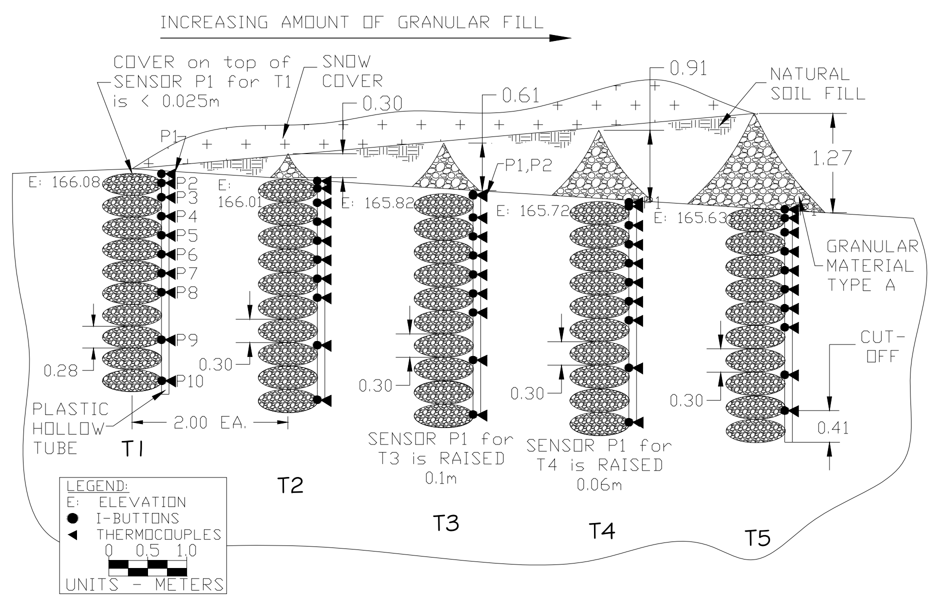

Figure 3. Pier profile layout

Matrix soil was used to fill in areas around the Type Granular material placed on top of the piers (see Figure 3 idealized representation). Reportedly, snow cover was present intermittently from January through May, 2008. Precipitation records described later were obtained from Weather Office (accessed 05/15/2008).

Methods

A total of eight piers were installed and evaluated as part of this research investigation (pier numbers T1 through T5, 213, 278, and 279). Pier locations and spacing information is provided in Figures 2 and 3.

Temperature Sensors

An experimental test plan was devised to evaluate temperature profiles for five of the test piers. Programmable I-Button temperature sensors and thermocouples were used for temperature monitoring.

Figure 4. Temperature sensor installation

Temperature measurements were recorded for the duration of the evaluation period and at measurement intervals as shown in Figure 3 to a depth of about 3 m (10 ft). Once the piers were constructed, a 130 mm (5 in) diameter hole was drilled adjacent to each pier to the bottom of the pier. A plastic pipe 51 mm (2-inch) internal diameter containing the temperature sensors was then inserted down each hole. The sensor notation is such that P1 indicates the shallow position and P9 – the deepest position as shown in Figure 3. Holes were drilled in the pipe to expose the temperature sensors at selected depths. The pipe was subsequently filled with sand. After inserting the pipe and sensor array, the drilled hole was backfilled with well-graded, crushed aggregate and tamped by hand with a pipe section.

The sensor wires were raised to the surface for access to a data logger. I-Button temperature sensors were selected because they are relatively durable, cheap, and programmable. Thermocouples are also inexpensive and cover a relatively large spectrum of temperatures, but are not programmable without a data logger system. For this study, thermocouples were included only as a reference to the I-Button measurements. I-Button temperature measurements were recorded hourly during the monitoring period while only a few measurements were recorded using the thermocouples. Figure 4 shows pictures taken during temperature sensor installation.

Figure 5. Dynamic cone penetrometer test (left), (b) Light weight deflectometer test (right)

Pier Stiffness Measurements

Immediately after pier installation in January and after the winter thaw in May, several piers were tested using a 300 mm plate diameter Zorn Light Weight Deflectometer (LWD) (Zorn, 2003) to determine pier stiffness, 300 mm diameter static plate load test (White et al., 2007) to determine pier stiffness, and Dynamic Cone Penetrometer (DCP) (ASTM, 2003) to evaluate strength. Figure 5 shows the LWD and DCP testing devices and setup used in the investigation.

Results

Temperature Measurements

Figures 6 and 8 provide the temperature time histories for piers T1, T2 and T3. The top of pier I-Button temperature measurements (sensor P1) showed that temperature fluctuations closely reflected changes in air temperature and that the aggregate cover provided some insulation from cold temperatures. Careful inspection of the raw temperature data files revealed that the unprotected pier (T1) was subjected to 9 freeze/thaw cycles during the measurement period. Further, the number of freeze/thaw cycles decreases rapidly with increasing fill cover, and those piers with at least 0.9 m (3ft) of fill cover did not experience freezing.

Table 1. Comparison measurements for pier stiffness and number of freeze/thaw cycles

Pier	11-Jan-08			7-May-08			E_{LWD} Ratio After/ Before	Granular "Type A" Cover Thickness (m)	Number of Freeze/ Thaw Cycles
	k_{LWD} (MPa/m)	$k_{PLT(i)}$ (MPa/m)	DCP Index (mm/blow)	k_{LWD} (MPa/m)	$k_{PLT(i)}$ (MPa/m)	DCP Index (mm/blow)			
T1	40	103	—	64	80	—	1.63	0	9
T2	28	56	2	59	—	7	2.11	0.3	3
T3	37	83	3	57	—	10	1.53	0.6	1
T4	51	141	—	73	—	—	1.45	0.9	0
T5	69	116	2	45	—	11	0.65	1.2	0
213	41	—	—	46	—	—	1.13	—	—
278	156	—	—	123	—	—	0.79	—	—
279	61	—	—	60	—	—	0.98	—	—
Average	60	100	2	66	—	9	1.28	—	—

Notes: k_{LWD} = Stiffness determined from 300 mm diameter plate Zorn light weight deflectometer; $k_{PLT(i)}$ = Initial loading stiffness determined from 300 mm diameter static plate load test for a stress range of 0.2 to 0.4 MPa.

k_{LWD} and k_{PLT} was calculated using Equations (1) and (2)

$$k = \frac{\sigma_o}{d_o} \tag{1}$$

$$\sigma_o = \frac{F}{\pi \cdot r^2} \tag{2}$$

where k – stiffness (MPa/m), d_0 – measured settlement (mm), σ_0 – applied stress (MPa), F – applied force (kN), and r – radius of the plate = 150 (mm)

F - force for LWD test was calculated using Equation (3) (see White et al., 2007):

$$F = \sqrt{2 \cdot m \cdot g \cdot h \cdot C} \tag{3}$$

where m – mass of falling weight = 10 (kg), g – acceleration due to gravity = 9.81 (m/s^2), h – drop height = 0.71 (m), C – material stiffness constant = 362,396 (N/m)

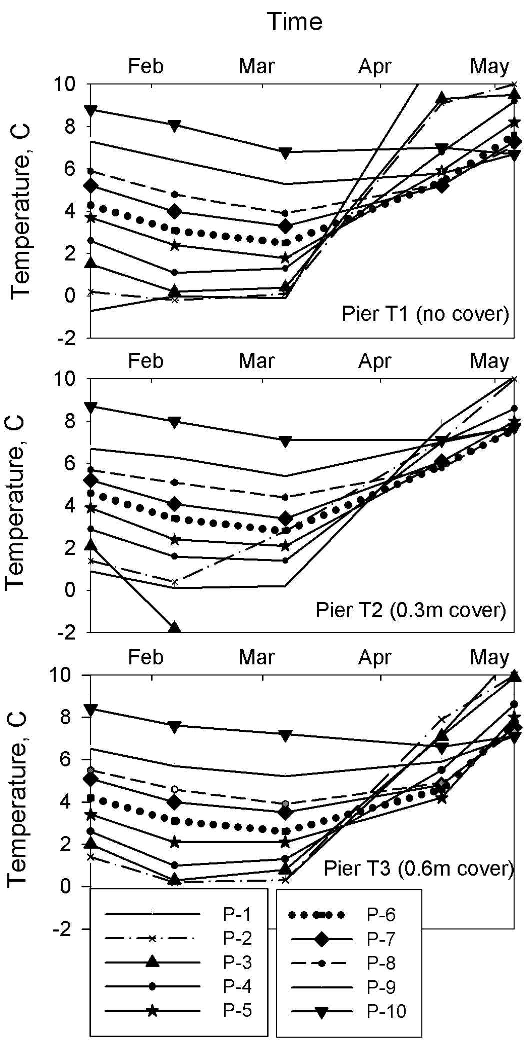

Figure 6. Thermocouple temperature sensor records for piers T1, T2, T3

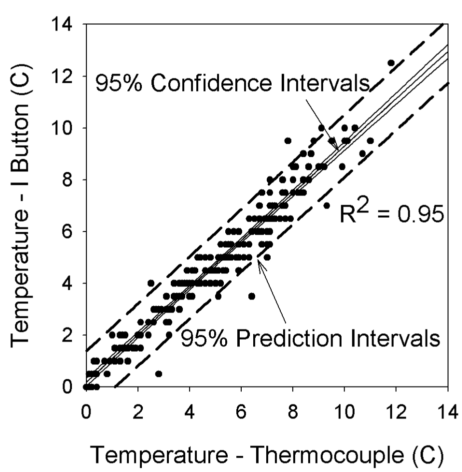

Figure 7. Thermocouple versus I-Button temperature correlation

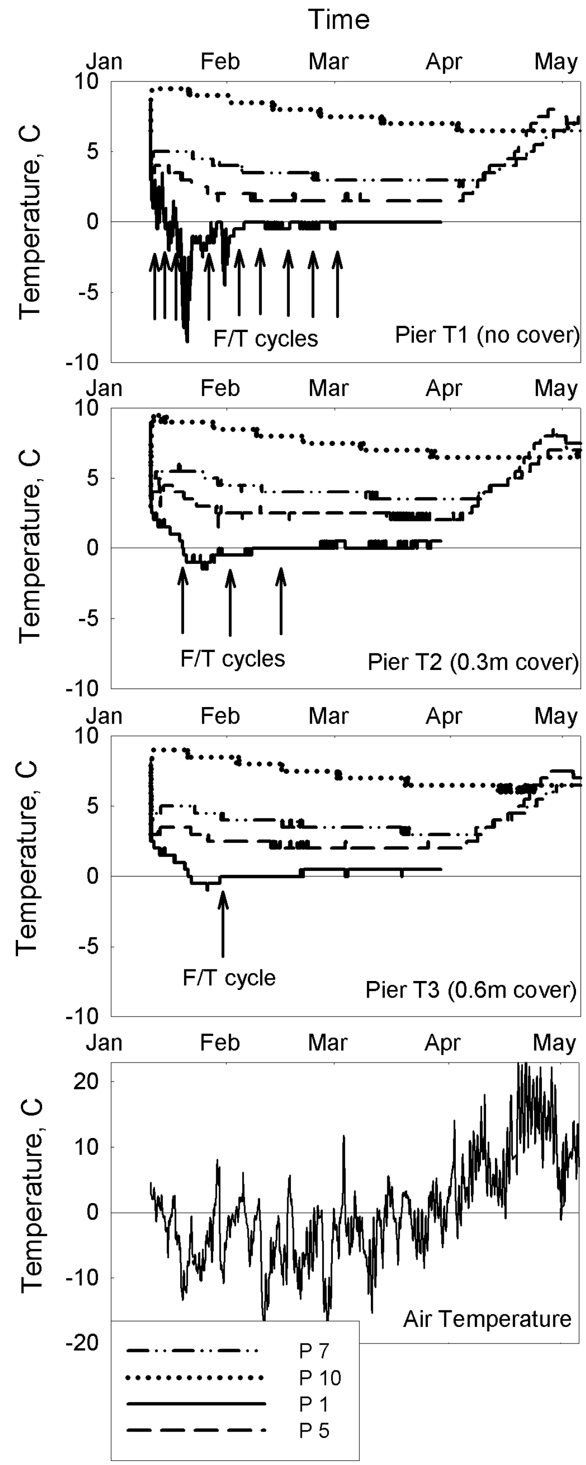

Figure 8. I-Button temperature sensor records for piers T1, T2, T3 and air temperature

Table 1 summarizes the number of freeze/thaw cycles for piers T1 through T5. Figure 6 provides temperature measurements from the thermocouples showing similar trends as the I-Button measurements. The sample frequency for the thermocouples, however, was not sufficient to capture the number of freeze/thaw cycles, but did verify the I-Button measurement values. Figure 7 provides a comparison between the I-Button and the thermocouple measurements. Figure 9 highlights the coldest and warmest I-button temperature measurements during the measurement period. As expected, pier T1 experienced the largest temperature fluctuations. The thermocouple temperature measurements at different time intervals for piers T1 through T5 confirmed the observations from the I-Button measurements.

Figure 9 shows the top of pier temperatures for pier T1 and T5 and the difference between the top of pier temperature for piers T2 through T5 relative to T1 (no cover). Results show that the temperature fluctuated for pier T1 more than piers protected with cover material.

Also, the piers with cover material were generally warmer during cold events and cooler during above freezing warming trends. The results support the approach of using cover fill to insulate the piers from freeze/thaw cycles.

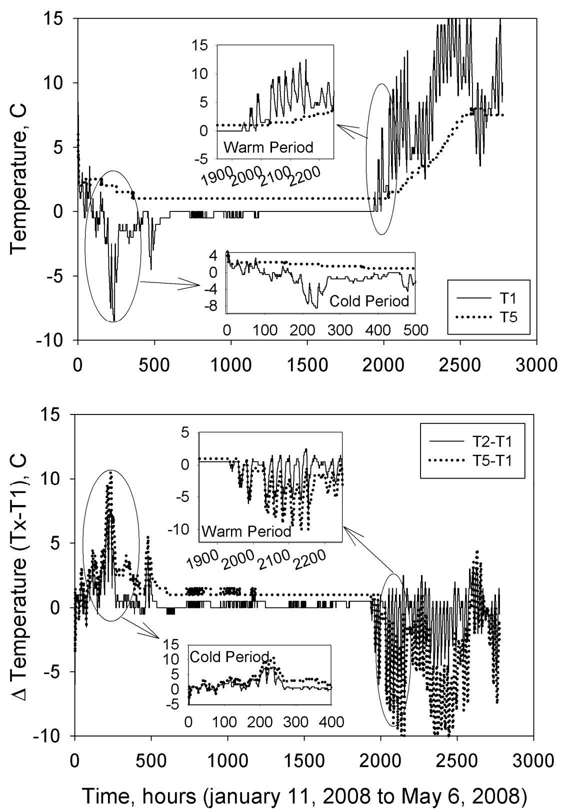

Figure 9. Comparison between top of pier temperatures during measurement period (top), and difference between test piers with cover and test pier T1 with no cover (+ indicates insulation) (bottom)

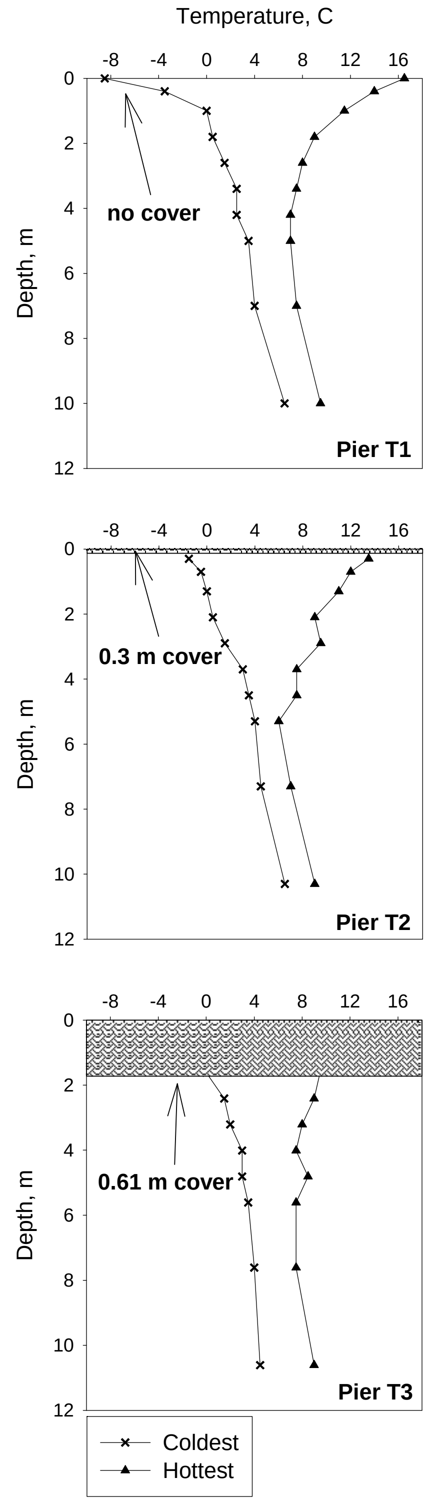

Figure 10. Extreme temperature profiles for piers T1, T2, T3 – coldest to warmest recorded

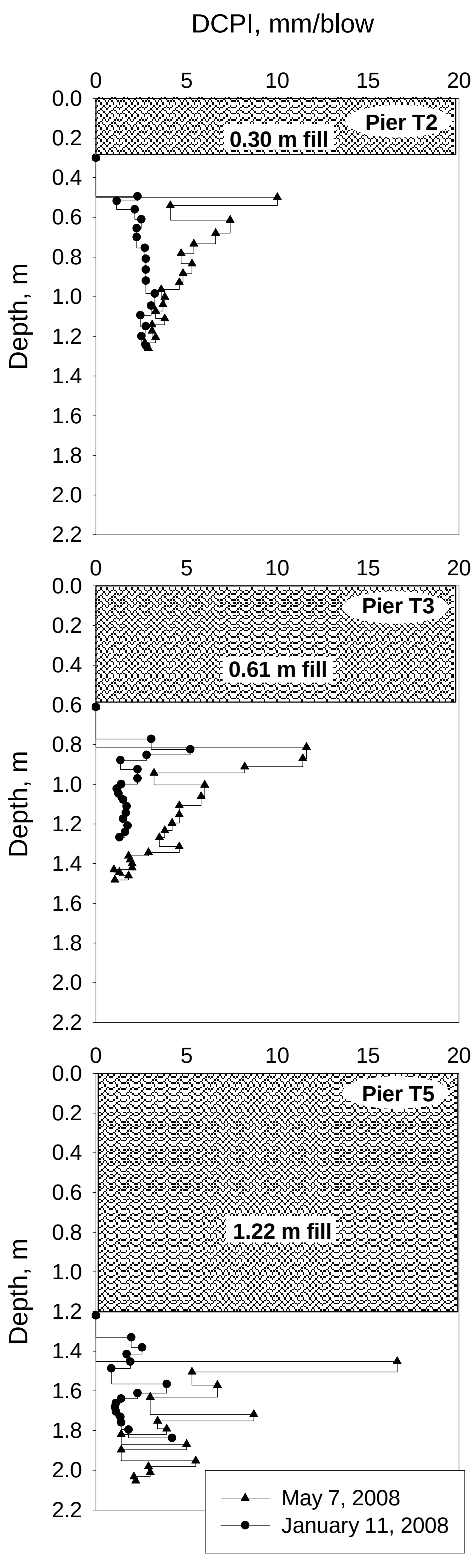

Figure 11. DCP index results for piers T2, T3, T5

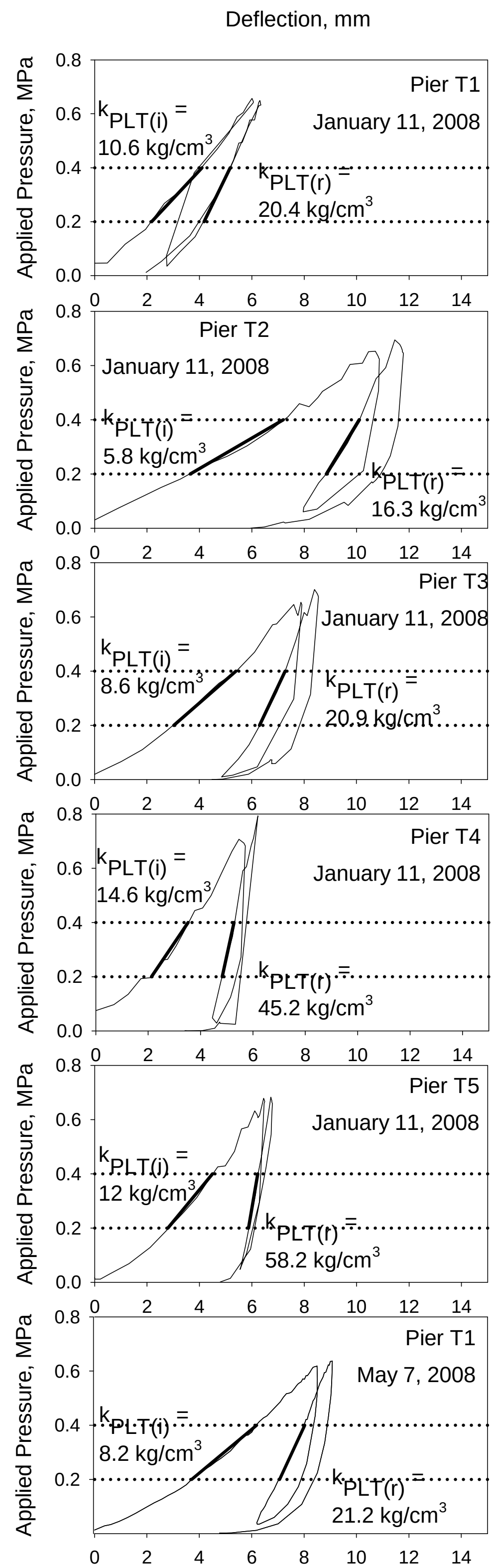

Figure 12. Stress-strain curves from 300 mm plate diameter static plate load tests ($k_{PLT(i)}$ – initial stiffness and $k_{PLT(r)}$ – reload stiffness)

The thickness of the fill cover should vary with the maximum frost depth regionally. For the location tested as part of this study conducted in the winter of 2008, 0.9 m (3 ft) of cover material was sufficient to prevent freezing at the top of the pier.

Pier Stiffness Measurements

Figure 13 shows pier stiffness values measured from the LWD (k_{LWD}) in January and in May 2008. Results show that the stiffness values (1) were generally higher in May than in January and (2) at the beginning and end of the monitoring period were similar for a given pier. The overall average increase in pier stiffness from January to May was by a factor of about 1.3. Stiffness values were more variable in January than in May (coefficient of variation = 68 versus 37 percent). The stiffness values do not correlate well to the number of freeze/thaw cycles or fill cover thickness. DCP index values for three piers are shown in Figure 11.

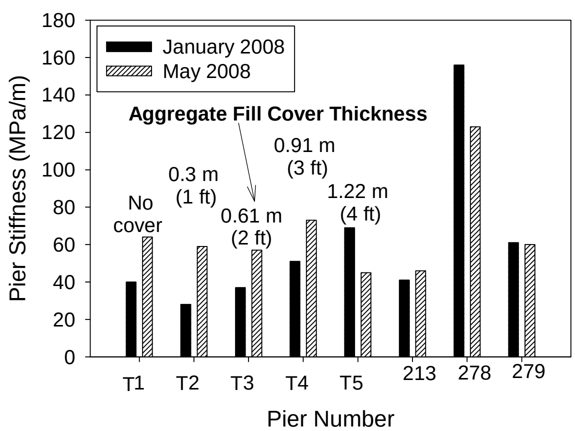

Figure 13. Comparison of E_{lwd} stiffness values before and after winter (soil cover information provided for T1 – T5, unknown for piers 213, 278, and 279))

DCP results show that the tops of the piers generally provided higher penetration resistance, although tests in May showed slightly lower overall penetration resistance. Stress-deflection curves from 300 mm static plate load tests are provided in Figure 12. Stiffness values from the static plate load tests were generally higher than for the dynamic LWD tests. Only one plate load test was performed in May due to difficult site conditions and positioning the load test truck over the piers.

Key Findings

In brief, the significant findings from this study can be summarized as follows:

1. Granular ("Type A") fill cover over piers reduces the number of freeze/thaw cycles experienced at the top of the pier. At the test site, 0.3 m (1 ft), 0.6 m (2 ft), 0.9 m (3 ft) and 1.2 m (4 ft) reduced the number of freeze/thaw cycles from 9 to 3, 2, 0, and 0, respectively.
2. Light weight deflectometer measurements shows that the piers became stiffer during the measurement period (January to May 2008) by a factor of about 1.3. However, the as-built pier stiffness was more variable than the changes in stiffness resulting from the freeze/thaw condition.

The results presented above provide new information documenting pier temperature profiles, insulating effect of fill cover, and relative pier stiffness values before and after winter. However, these results should be considered specific to this particular project site. Efforts to mitigate the potential for freeze/thaw in the top of exposed piers and surrounding matrix soil are warranted and may require new testing to document behavior.

References

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Acknowledgement

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