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Subgrade Freeze-Thaw Behavior at the Northern Mega Site

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Summary

In northern regions of North America, railroad tracks experience annual freeze-thaw cycles that can result in track geometry deterioration. To determine the substructure layers that contribute to surface track geometry deterioration and the mechanisms producing this movement, Transportation Technology Center, Inc. (TTCI) investigated the freeze-thaw behavior of railroad track substructure at the northern mega site (NMS) near Winnipeg, Manitoba from June 2016 to July 2017. The investigation measured soil temperature, dynamic wheel loads, and soil pressures at varying depths to gather insight into changes in soil behavior and response throughout the coldest portion of the year.

Three distinct timeframes were observed throughout the year, including: 1) thawed (mid-May to mid-December), 2) frozen (mid-December to early April), and 3) thawing (early April to mid-May). Each of these timeframes had distinct soil pressure behaviors.

During the thawed timeframe, the dynamic lateral earth pressures were consistent. The pressures were noticeably lower during 2017 suggesting that 2016 had higher pressures from residual stresses due to the installation process. During the frozen timeframe, the dynamic lateral earth pressures were erratic and had episodes of high pressures and low pressures. This is likely from the formation of ice lenses, frost heaving, and other freezing behaviors. During the thawing timeframe, the dynamic lateral earth pressures decreased with time, indicating a relaxation in the lateral stresses. The greatest decreases were in Layer 2 (silty sand) and Layer 4 (stiff clay).

The frost depth extended beyond 5 feet in depth and daily temperature fluctuations affected the top 18 inches. Track geometry measurements from the study period showed no significant geometry degradation so no conclusions can be made. A longer study period or site location with greater movement likely would be necessary.

The project was conducted by TTCI under the Association of American Railroads' (AAR) Strategic Research Initiatives (SRI) Program with cooperation from Canadian National (CN) Railway.

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INTRODUCTION

In northern regions of North America, railroad tracks experience annual freeze-thaw cycles that can result in track geometry deterioration. During the freezing period, the track substructure stiffens and can experience frost heave due to the accumulation of ice in underlying soil.[1] Silty soils tend to be the most susceptible. During the thaw period, the track substructure softens and can experience lateral deformation and other movement.

To better understand the freeze-thaw behavior of various substructure soils and how they contribute to track geometry deterioration, TTCI monitored a section of CN track near Winnipeg, Manitoba.

SITE SUBSTRUCTURE

The selected site comprises four substructure layers. The depths and a brief description of each layer are presented in Table 1.

Table 1. Substructure Layers

Layer	Depth* (thickness)	Description
1	0-28 in. (28 in.)	Dense fines-contaminated ballast
2	28-40 in. (12 in.)	Sand with silt, fine gravel, clay, dense
3	40-52 in. (12 in.)	Fine gravelly sand with silt and clay
4	52-36 in. (84 in.)	Stiff high plasticity clay

*Depth below ballast surface at tie (top-of-tie)

INSTRUMENTATION

Thermocouples, lateral earth pressure cells, and strain gages were installed to monitor soil behavior. Ten thermocouples (T1 through T10) were placed in the soil at six-inch vertical increments to measure soil temperatures. Four lateral earth pressure cells (P1 through P4) were placed at different depths to obtain static and dynamic lateral pressure with time. This can give insight into load distribution and lateral deformation. The strain gages were attached to the rail to measure wheel loads. This gives insight into axle weight and minimizes the influence of load variability from the dynamic lateral earth pressure measurements.

The depths of the instrumentation are listed in Table 2 and displayed in Figure 1. The second column refers to the depth below the ballast surface at the tie elevation and the third column refers to depth below the ballast surface at the instrument locations, since the ballast slopes downward on the instrumented shoulders. Differences are due to the thermocouples being installed 80 inches laterally from the tie (16-inch elevation difference) and the third and fourth pressure cells at 24 inches laterally from the tie (6-inch elevation difference).

Table 2. Instrumentation Locations

Sensor No.	Depth (Tie)	Depth (Shoulder)	Substructure Layer
T1	16 in.	0 in.	1
T2	22 in.	6 in.	1/2
T3	28 in.	12 in.	2
T4	34 in.	18 in.	2/3
T5	40 in.	24 in.	3
T6	46 in.	30 in.	3/4
T7	52 in.	36 in.	4
T8	58 in.	42 in.	4
T9	64 in.	48 in.	4
T10	70 in.	54 in.	4
P1	30 in.	30 in.	2
P2	44 in.	44 in.	3
P3	50 in.	44 in.	3
P4	62 in.	56 in.	4

*Ballast (Tie) is the depth from the ballast surface at tie

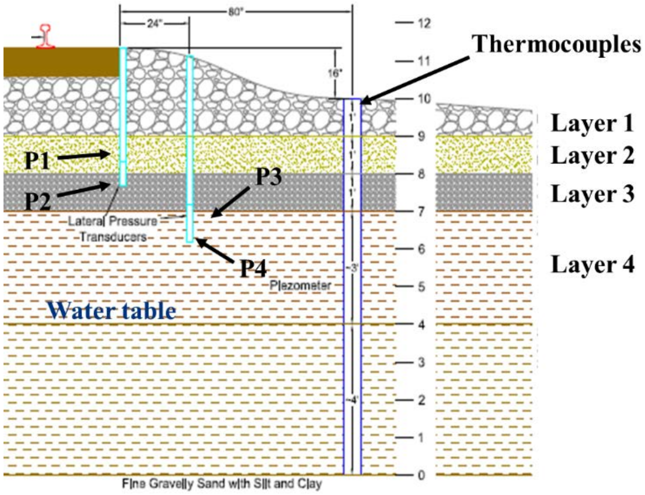

Figure 1. Diagram of Instrumentation

RESULTS

Static monitoring occurred from June 14, 2016 to July 14, 2017, and dynamic monitoring occurred from September 12, 2016 to June 29, 2017.

To minimize the influence of wheel load variation on the dynamic lateral earth pressures, the peak dynamic lateral pressures (static pressures baselined to 0.0) were divided by wheel load values to give Lateral Pressure Ratio (LPR).[2]

General Observations

General observations from the thermocouples, depicted in Figure 2 and LPR displayed in Figure 3 over the entire monitoring period show three distinct timeframes:

1. Thawed: mid-May to mid-December. Soil temperatures above 32°F with consistent LPR values.

2. Frozen: mid-December to early April. Soil temperatures below 32°F with erratic high and low LPR values.
3. Thawing: early April to mid-May. Soil temperatures at 32°F with initially high LPR that drop with time.

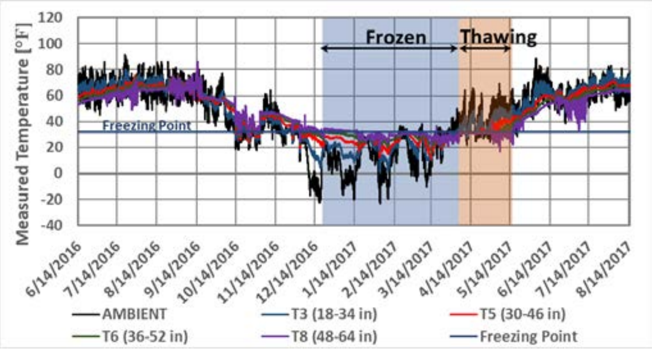

Figure 2. Ambient and Soil Temperatures with Time

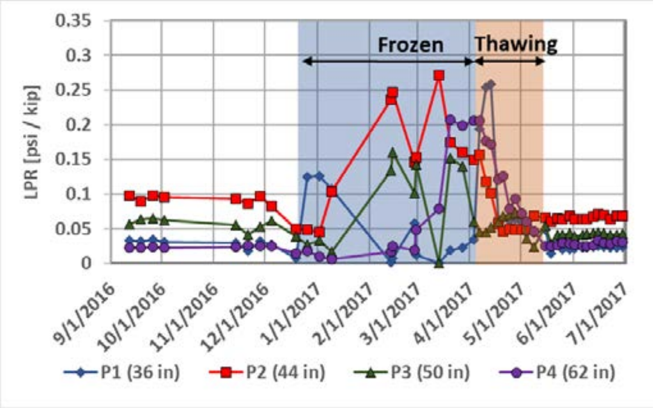

Figure 3. LPR with Time

The thermocouples and LPR values show a general agreement in the testing period timeframe based on varying depths.

All 10 thermocouples experienced freezing indicating the frost depth extends below 5 feet. The upper soil layers appeared to both freeze and thaw first, suggesting that a thawed surface in the spring may not indicate a thawed subsurface. Between early April to mid-March, the soil temperatures stabilized at 32°F, indicating thawing with the presence of both ice and water conditions. Daily temperature fluctuations affected the soil to a depth of 18 inches (1.5 feet) and the soil below that depth experienced minimal daily fluctuations. Freezing front advancement may have been slowed by the presence of a water table at the Layer 3/4 interface shown in Figure 1.

Thawed LPR Values

The average LPR value during the thawed period for 2016 and 2017 is shown in Figure 4. For both years, the highest LPR values were measured by P2 and P3. This suggests that Layer 3 (gravelly sand) from P2 and P3 shows the highest dynamic response compared to Layer 2 (silty sand) from P1 and Layer 4 (stiff clay) from P4.

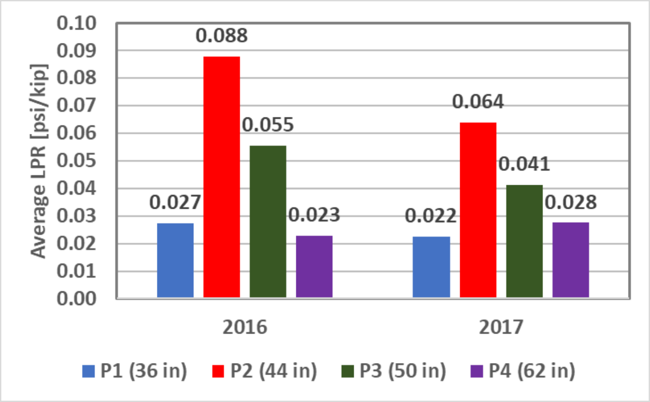

Figure 4. 2016 and 2017 Thawed Average LPR

Second, the P2 and P3 average LPR values are noticeably lower in 2017 than 2016 (~35 percent drop). Some change is anticipated every year from particle rearrangement, compaction, and lateral deformation, but the high 2016 values are likely from residual stresses during pressure cell installation. These residual stresses would be released during the freeze-thaw cycle and not appear the following year.

Thawing LPR Values

During the thawing time period of early April to mid-May, all four lateral pressure transducers experienced similar behavior in which the lateral pressures started at a high value and then decreased to the thawed LPR value. The beginning and end of this drop agrees with 32°F thermocouple measurements at similar depths.

Figure 5 is an example of this behavior in which the LPR starts at 0.21 and ends at 0.03, a drop of 0.18 (87 percent). This relaxation of stresses could indicate lateral movement or thawing mechanisms.

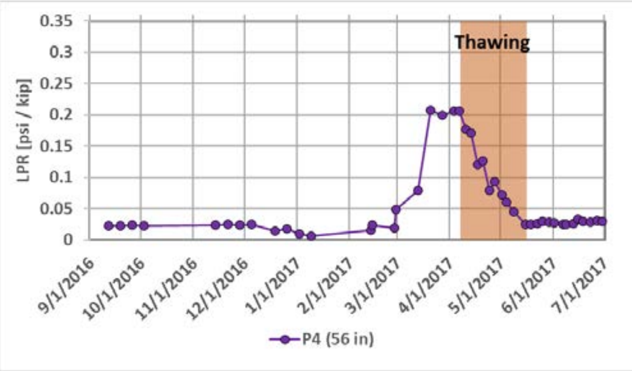

Figure 5. P4 LPR during Thawing Time-Frame

The drop in LPR during thawing, referred to as drop magnitude (left y-axis) and percentage (right y-axis) is illustrated in Figure 6. The results show the largest drop magnitude occurred in P1 and P4, correlating to Layer 2 (silty sand) and Layer 4 (stiff clay).

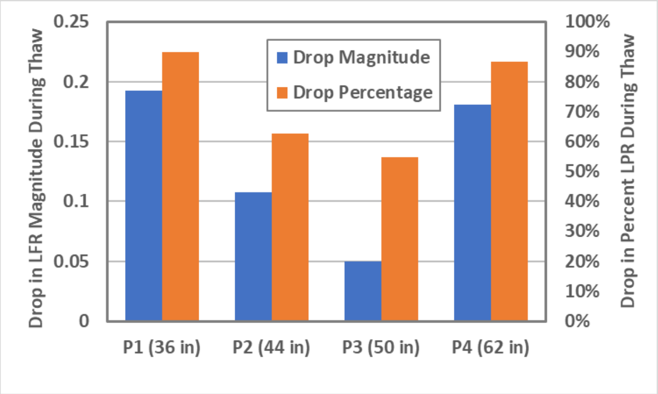

Figure 6. Drop in LPR during Thawing Timeframe

TRACK GEOMETRY

The final objective was to correlate the dynamic lateral pressure results with track geometry measurements. Track geometry was taken four times within the general timeframe of the study: April, August, and November 2016; and April 2017. Vertical surface (profile), alignment, and cross level were compared. To align the various curves, a road crossing about 487 feet from the site was used as a fixed reference point.

An example of left rail vertical surface is displayed in Figure 7. The results show minimal track geometry degradation over the year of measurements with changes of less than 0.05 inch.

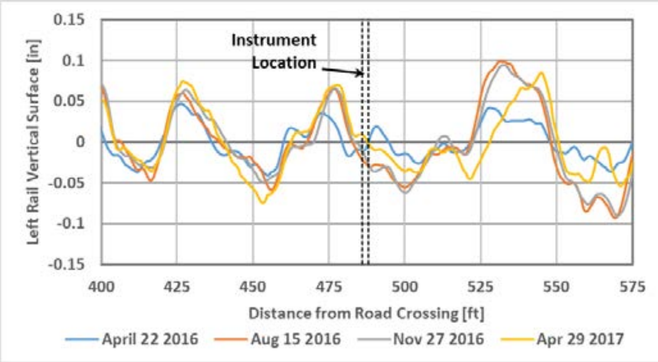

Figure 7. Vertical Surface of Substructure Site

The other track geometry measurements showed similar results. This does not allow for a comparison between the dynamic lateral pressure and track geometry, and additional data would need to be collected and analyzed. It is also possible that movement occurred between measurements and returned to their original position in the case of frost heave.

CONCLUSIONS

The testing results showed the following:

- Three distinct timeframes were observed throughout the year, including: 1) thawed (mid-May to mid-December), 2) frozen (mid-December to early April), and 3) thawing (early April to mid-May). Each of these timeframes had distinct soil pressure behaviors.
- During the thawed timeframe, the dynamic lateral earth pressures were consistent. The pressures were noticeably lower during the 2017 year than 2016 suggesting that the 2016 year had higher pressures from residual stresses due to the installation process.
- During the frozen timeframe, the dynamic lateral earth pressures were erratic and had episodes of high pressures and low pressures. This is likely from the formation/heaving of ice lenses and other freezing behaviors.
- During the thawing timeframe, the dynamic lateral earth pressures decreased with time, suggesting a relaxation in the lateral stresses. The greatest decreases were in Layer 2 (silty sand) and Layer 4 (stiff clay).
- Frost depth extended beyond 5 feet and daily temperature fluctuations affected the top 18 inches.
- Track geometry measurements from the study time-frame showed no significant geometry degradation so no conclusions can be made. A longer term study that includes inclinometers to measure lateral slope movement would likely be necessary.

References

1. Li, D., Hyslip, J., Sussmann T., and Chrismer, S., 2016. *Railway* Geotechnics. CRC Press. Boca Raton, FL.
2. Terzaghi, K., R. Peck, and G. Mesri. 1996 *Soil Mechanics in Engineering Practice*. John Wiley and Sons. New York.