

The work described in this document was performed by Transportation Technology Center, Inc., a wholly owned subsidiary of the Association of American Railroads.

### Key Findings:

- In situations with observed standing water, ditching or other drainage methods could remove the surface water before it freezes.
- Urethane foam injection technology could be used to insulate an identified frost-susceptible region.
- Excavation methods such as cut-and-replace, cementation, and installing extensive drainage methods for removing subsurface water are potential remediation options.

# Potential Frost Heave Detection and Remediation Methods

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In a multi-year study, [Transportation Technology Center, Inc. \(TTCI\)](#) is working with Canadian National (CN) at the northern megasite near Winnipeg, Manitoba to improve methods of detecting and remediating frost heave. The first phase of the project is to review the railway and highway experience to determine what methods can be adopted by the railroad industry. This includes conditions that can produce frost heave, methods that can be used for detection, and potential remedial solutions.

The review showed that the majority of highway experience would be difficult to transfer to railroads because of the need to shut down track for extended periods to complete excavation. However, there is potential for detection and remediation solutions. For detection, multiple track geometry runs during winter and gathering local feedback could help identify frost heave problem areas. For remediation, multiple solutions that avoid long track shutdowns exist, such as ditching, injections, and drainage, but the effectiveness will be site dependent.

Through literature review, TTCI identified three causal factors for frost heave:

- Frost heave-susceptible soils. While frost heave is possible in most soils, severe frost heave is most prevalent with silts, fine sands, and lean clays.
- Subfreezing temperatures in the soil.
- A source of water.

In general, system-wide detection methods are not used, and identification of problematic locations typically is based on local experience. The review showed no available technology as being proven at predicting frost heave based on the three conditions listed. Without new track-based inspection methods, a potential system-wide method could be developed by using historical data from multiple winter track geometry runs along with local knowledge from track supervisors. For sites that require remediation, additional data can be generated using soil maps, soil exploration, and ground penetrating radar (GPR).

Frost heave is a common substructure problem in Canada and the northern regions of the United States. It involves the vertical heaving and settling of track which can lead to track geometry issues and even be a safety risk in severe conditions. In addition, it is difficult to maintain once frost heave sets in because of the progressive nature of frost heaving, the frozen condition of the track, and the difficulty of lowering track in specific regions.

Due to these challenges, it requires an effort to improve detection and remediation techniques. Currently, detection is performed using visual, ride quality metrics, or geometry car measurements. For mitigation and remediation, the primary method is the use of salts, which lower the freezing temperature of the water in the soil. However, this method can be limited in effectiveness and presents some possible environmental issues.

### MECHANISMS AND CONDITIONS

The mechanism producing frost heave is essentially due to the freezing of excess moisture in the subgrade soil into ice lenses. These ice lenses cause the soil and track above it to heave, producing frost heave.

A typical frost heave situation involves a standing water table in which excess water flows upwards due to capillary rise. The amount of capillary rise and the ability for the water to flow upwards depends on the soil type. As the freezing front moves downward, the water at the freezing front freezes and accumulates into an ice lens (see Figure 1).<sup>3</sup> As the freezing front continues downward, multiple layers of ice lenses can form, producing significant surface heave.<sup>1</sup>

As stated, literature review found that three conditions are required for frost heave to occur: frost-susceptible soils, subfreezing temperatures in the soil, and a source of water,<sup>1-3</sup> Without all three conditions, frost heave cannot occur, so mitigation and remediation requires only the elimination of a single factor.

The first condition, frost-susceptible soils, generally refers to the presence of silty material. Silts are defined as soil that have grain sizes ranging from 0.06 to 0.002 mm. Silts are more frost-heave susceptible than sands and clays because silts have a balance between susceptibility for capillarity rise and permeability. This means the silts are able to create enough capillary rise and also have a high enough permeability for the

moisture to migrate upward towards the downward freezing front. Sands have high permeability but low susceptibility to capillary rise; while water can freely flow through sand, there is not normally enough capillary rise for the moisture to migrate upwards. Clays have high capillary rise but low permeability; thus, while the clays will attract moisture upwards, the moisture will not be able to travel through the clay to get to the freezing front.

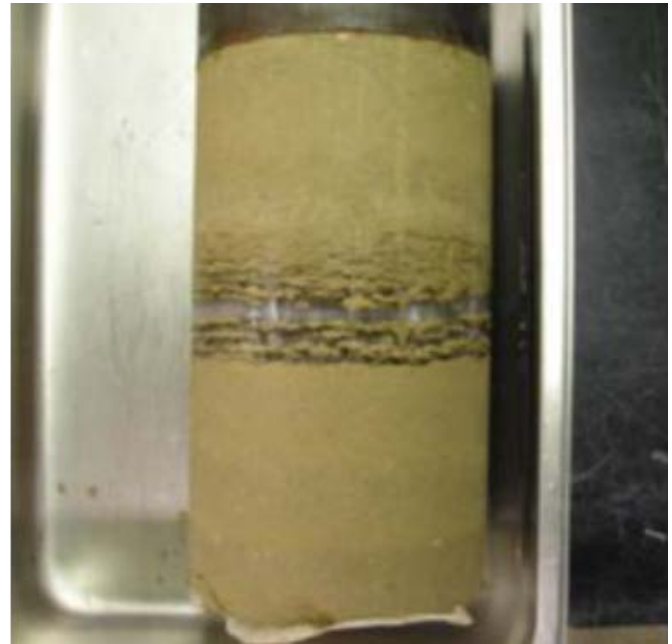


Figure 1. Frost heave core section

While silts are generally the most susceptible to frost heave, fine sands, lean clays, or a well graded soil also can be at risk. A diagram showing frost-susceptible soils is displayed in Figure 2.

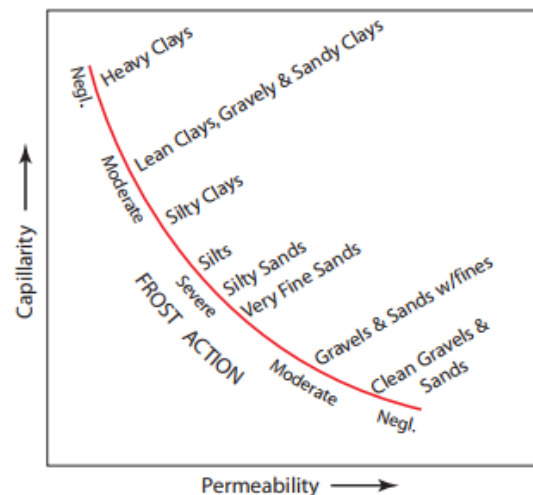


Figure 2. Frost-Susceptible Soils<sup>4</sup>

The second condition, subfreezing soil temperature, is self-explanatory because freezing conditions are required to freeze the moisture within the subgrade soil. Typically, the freezing front moves downward, which produces the layering of ice lenses. A secondary problem is the downward thawing front in spring that can trap surface moisture and soften the upper track layers.<sup>1</sup>

The third condition, a source of water, is required because excess moisture is needed in order to accumulate into an ice lens. Capillary action in soil is not strong enough to pull moisture naturally present in the soil, so excess water, typically a standing water table, is required for ice lens formation. The highway literature suggests a water table up to 10 feet (3.3 meters) from the surface can produce significant frost heave and that minor frost heaving can occur from water tables up to 20 feet (6.6 meters) in depth.<sup>2</sup>

## DETECTION

With three required conditions for frost heave and successful remediation only requiring the elimination of one condition, a system-wide frost heave detection system ideally should attempt to identify locations with all three conditions. This section lists the available methods for detection.

Identification of the first condition, frost-susceptible soils, is possible using the following techniques.

- Soil maps and/or highway data: Soil maps from the United States Geological Survey (USGS) or Canadian equivalent are widely available for areas throughout the U.S. and Canada and often highways are constructed near railway lines. This data does not necessarily give an accurate picture of what is directly below the railroad track.
- Soil exploration: The most reliable method of determining the soil type underneath the track would be a soil exploration survey that takes physical samples from below the track. This will give the most reliable information but will be the most expensive and time consuming.

A third possible method that has not been used would be geoscopes. This new method of track inspection involves using a dynamic cone penetrometer (DCP) to drill a rod into the ground and then lowering a video camera through a slotted rod up to a depth of 15 feet or greater. This method could potentially allow for video evidence of soil type at an exact

location under the track but would require in-house interpretation and time for each test to be conducted. This method would need to be tested and verified before implementation.

The second condition, subfreezing soil temperatures, can be determined from highway experience. Temperature probes can also be used if an exact temperature is required.

The third condition, presence of water, also is a difficult condition to assess and also may fluctuate during the year. Potential methods of determining water are listed below.

- Visual inspection: Standing water can be identified if nearby ditches or regions are filled with water.
- Soil exploration: The most reliable but most expensive method of determining moisture is through a soil exploration survey.

However, these methods only look at the surface (visual inspection), are invasive (soil exploration), and/or are unable to be implemented on a track-based system.

Track-based substructure inspection methods are GPR and Light Detection and Ranging (LIDAR) systems. GPR is used to assess fine and moisture levels in ballast but has not been used to differentiate between subgrade soil types or reliably identify water tables. LIDAR could be used to identify surface standing water but does not give insight into water tables below the surface.

## REMEDICATION

Prevention of frost heave through remedial methods only need to mitigate against one of the three conditions. The highway industry utilizes multiples techniques, including the following:<sup>2</sup>

- Cut and replace: A common highway technique for removing the frost-susceptible soils is to cut and replace. This is an expensive operation and would require complete track shutdown during remediation.
- Cementation: A method for reducing the frost-susceptibility of existing soils is to use cementation methods such as cement injections, lime, and other similar products. These could be injected similar to existing grout injection methods.
- Salts: A common method currently used by multiple railroads is salts. This technique will lower the freezing temperature of the water in the soil. However, this must

be done prior to freezing and brings up potential environmental questions.

- **Insulation:** A method used by some highways is to insulate the frost-susceptible soil from the downward moving freezing front is with urethane foam or mats.<sup>3</sup> This insulating layer can be placed using existing equipment that could be modified to inject the insulating foam.
- **Drainage:** If standing water is observed near the surface, ditching presents a potential option to remove the excess water. Wicking fabric also could be installed but would require track excavation.<sup>5</sup>

An additional method for railways is shimming.<sup>1</sup> This method could be used to raise the surrounding track to the elevation of the frost heave region. The shims must also be removed in spring during the thawing.

### POTENTIAL METHODS

The literature review suggests that a system-wide frost heave prediction tool is not feasible with the current technology due to the difficulty of differentiating soil types and identifying water tables using track-based, non-invasive methods. Without new methods, a potential system-wide method would be running multiple track geometry measurements throughout the winter months and using the data to identify frost heave regions. This could be supplemented with local experience from track supervisors. After categorizing the frost heave locations, remediation could be prioritized for the following year. A technology scan of current and potential methods to develop new track-based inspection technologies that could better identify track at risk for frost heave could also be useful.

If a location is identified for remedial action, multiple remediation methods could potentially be used but the decision will need to be based on the site-specific conditions that would dictate effectiveness of the remediation. More in-depth site investigations may be useful for optimizing the design. Due to the desire for remediation without shutting down the track, there is a potential to improve injection methods to further expand the viability of injection-based remedial solutions.

### MOVING FORWARD

The next phases of this multi-year project are to instrument a site that has historical frost heave issues, remediate this site with one or multiple remediation techniques, and investigate and attempt to implement methods of detecting frost-heave susceptible sites on a system-wide basis.

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