

INVESTIGATION OF TIE PLATE ICING/ICE JACKING for Transport Canada

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Executive Summary

MxV Rail (formerly TTCI) investigated and documented the tie plate icing/ice jacking during three field inspection trips to three railroads in cold weather conditions. The research detailed in this report was completed between January 2022 and April 2022 under Transport Canada contract T8009-180251/001/TOR, and the work has led to an improved understanding of the inspection, formation mechanism, identification, and remediation of tie plate icing. The findings from this research will be used in future phases to perform modeling, laboratory testing, and in-track testing used to further understand and remediate tie plate icing.

The overall goal of this research is to understand 1) the root causes and effects of tie plate icing on track performance and train operation safety, 2) potential methods for identification and monitoring of tie plate icing, and 3) potential remedial methods and actions for tie plate icing. Case studies (field inspections) were conducted at the railroad sites where tie plate icing problems occurred in the past to gain an understanding of the issue and acquire the experience from the railroads.

The key findings from this study include the following:

- Tie plate icing is difficult to identify in track with covered snow. Typical indications of the occurrence of tie plate icing include “black marbling” or “cauliflowering” of snow by rail movement, changes in track gage, and rail cant.
- Tie plate icing is believed to be caused by a combined effect of track conditions and weather conditions. The areas of concern, including curves, joints, turnouts, road crossings, bridge approaches, etc., are typically associated with wood ties with cut spikes and significant rail movements. Poor tie condition and fouled ballast are often found to be in the areas of tie plate icing.
- Two conditions that could cause tie plate icing were mentioned by railroads: rail jacked by snow and rail jacked by ice. The first condition happens when that snow gets blown against the bottom of the rail and then becomes packed layer by layer to jack up the rail. The second condition occurs when weather conditions create freeze-thaw cycles where snow/ice melts and becomes trapped in the gap between the bottom of the rail and tie plate and freezes again.
- A preliminary finite element (FE) model was developed for the next phase of this study. This model consisted of a detailed rail-tie-fastening system capable of simulating the effect of tie plate icing on track performance.
- A brief conceptual laboratory test plan prepared for the next phase. However, this plan will need to be expanded and detailed with the steering committee and railroads.

Future work will focus on comprehensive modeling efforts, laboratory testing, and the development of remediation methods for in-track testing.

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1.0 INTRODUCTION

MxV Rail (formerly TTCI) investigated and documented the tie plate icing/ice jacking during three field inspection trips to three railroads in cold weather conditions. The research detailed in this report was completed between January 2022 and April 2022 under Transport Canada contract T8009-180251/001/TOR, and the work has led to an improved understanding of the inspection, formation mechanism, identification, and remediation of tie plate icing.

Snow and ice can impose hazards on the safety and integrity of both train operation and impact rail infrastructure. As a winter hazard, tie plate icing (also referred as ice jacking) has resulted in train derailments in the past¹⁻³ and needs to be thoroughly investigated and closely monitored. Tie plate icing occurs when ice builds up between the base of the rail and the tie plate. The ice buildup will cause the rail to sit vertically above the shoulder of the tie plate, leaving the fasteners as the primary means of providing resistance to lateral rail motion. Figure 1 shows the ice buildup lifting the rail and raising the spikes.



Figure 1. Ice buildup on tie plate¹

Tie plate icing is possible any time snowfall accumulates around the base of the rail and tie plates. According to the investigation by Canadian National Railway (CN), when the track is in a condition where the rail pumps up and down, creating a void under the rail and sucking snow around the base of the rail into the void. The snow in the void is then compacted and transformed into a layer of ice under the rail, lifting the base of the rail above the shoulder of the tie plate, placing the primary source of lateral restraint on the spikes. The spikes are not able to withstand the lateral loading, and they will eventually wear down, break, or fall out under load. The rail then pushes outward, allowing the wheels to fall between the rails. This process takes time to build up enough ice to lift the rail above the shoulder of the tie plate. Figure 2 presents this process as well as potential effects such as gage widening and reverse cant. In addition, CN

pointed out that wide-gage defects or broken spike derailments in the winter probably had ice jacking as an unrecognized contributing factor.²

The Transportation Safety Board (TSB) of Canada reported two train derailments due to snow and ice buildup underneath a rail. Both locations were on curves. Wide gage was found, but no urgent or near urgent defects were noted. The two locations had cut spike fastening systems with standard tie plates. The weather reports for the accident areas included several freeze-thaw cycles, and tie plate icing was found at both locations. The reports concluded that the development of tie plate icing was due to a combination of the weather conditions and the track conditions.^{1,3}

Reports from both locations also indicated that frequent pumping locations such as joints, curves, turnouts, diamonds, road crossings, bridge approaches, etc., could be areas of concern. Poor tie conditions or ballast fouling could also contribute to ice buildup along the base of the rail.²

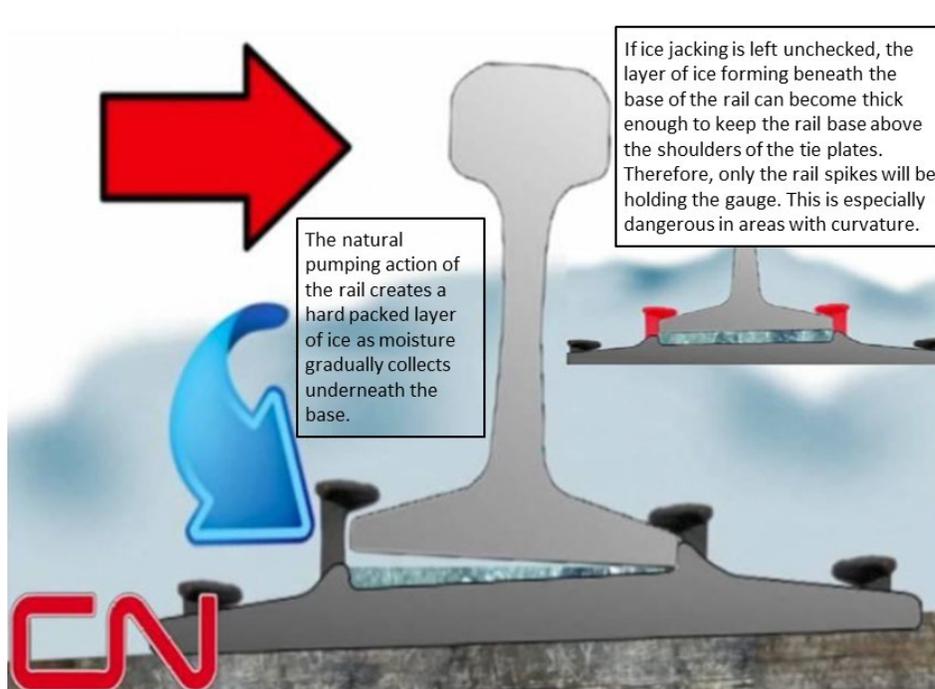


Figure 2. Development of ice buildup under the rail²

To date, both the formation and development of tie plate icing have not been fully investigated or understood. The effect of environmental and track conditions needs to be further studied to understand how these conditions contribute jointly to the issue. The rate of ice buildup between the rail and tie plate is not well understood and deserves further investigation.

According to the reports from the TSB and railroads, the problem of tie plate icing is difficult to detect, especially under the cover of snow. Improvements to maintenance practices and standards can be made to facilitate early detection of this issue or early locating of areas of concern for closer inspection. Special safety action may need to be taken in areas susceptible to tie plate icing during winter operations, but while several potential remediation methods may fix or alleviate this issue, none of these methods have been chosen as a proven method, indicating further study on appropriate remediation methods for tie plate icing is warranted.

In this phase of research, field inspections were performed to investigate and improve the understanding of the issue of tie plate icing to create better focus for future studies. The summary of the trip findings and future work are included in this report.

2.0 CASE STUDIES (FIELD INVESTIGATION)

Three cold season inspection trips were taken to make observations and document tie plate icing conditions at the sites of interest where tie plate icing had occurred in the past. The three sites of interest were on three different railroads: two sites were in Canada (one on Canadian Pacific (CP) and one on CN) and the third site was in the United States (Genesee & Wyoming). Weather conditions and site and track characteristics (rail size, tie type and condition, fastening type and condition, track curvature, drainage condition, etc.) were documented at each location. Lateral track strength measurements were taken for some locations with gaps between tie plates and rails during the trips. Other locations generally had great lateral track gage strength with minimum gage widening. Engineers from MxV Rail also spoke with the local track manager/roadmaster and gathered information about the maintenance practices and inspection methods related to the tie plate icing issue.

2.1 Trip 1: Genesee & Wyoming, Fergus Falls, MN, USA (February 15-18, 2022)

The first location was Genesee & Wyoming, Otter Tail Valley Railroad (OTVR), a Class III railroad operating 64 miles of track between Moorhead, Minnesota (MN), USA and Fergus Falls, MN, USA with some short branch lines near Fergus Falls. The gross rail load of cars on this railroad was typically 286,000 pounds. Several grade crossings with history of tie plate icing were identified by OVTR and inspected on February 16 and 17, 2022.

On February 16, the inspection was performed at a grade crossing on a tangent track in Fergus Falls, MN (46.2802042, -96.0668825). The OTVR identified this location as the best potential site for tie plate icing since the area was a low track spot, and the track did not have good drainage. The rail size was 115 pound/yard, and the fastening system was made up of 14-inch plates with two rail spikes. The speed limit of the inspection site was 10 miles per hour. The inspection trip began around 9:30 a.m. The weather was sunny at the beginning and slightly snowy in the afternoon. The temperature varied from 11°F to 26°F during the day. The grade crossing was covered by snow/ice (Figure 3).



Figure 3. Grade crossing at 46.2802042, -96.0668825

The top 3–5 inches of snow were easy to remove. However, a mixture of snow and dirt was packed solid near the bottom of the rail web (red circle in Figure 4). Since the grade crossing was at a low spot and near a busy in-town vehicle road, muddy ballast with very poor drainage was found at the location. Due to the frozen dirt and ice around the rail seat area, it was difficult to dig to the bottom of the rail and tie plate. Only one rail seat area was fully exposed for inspection.

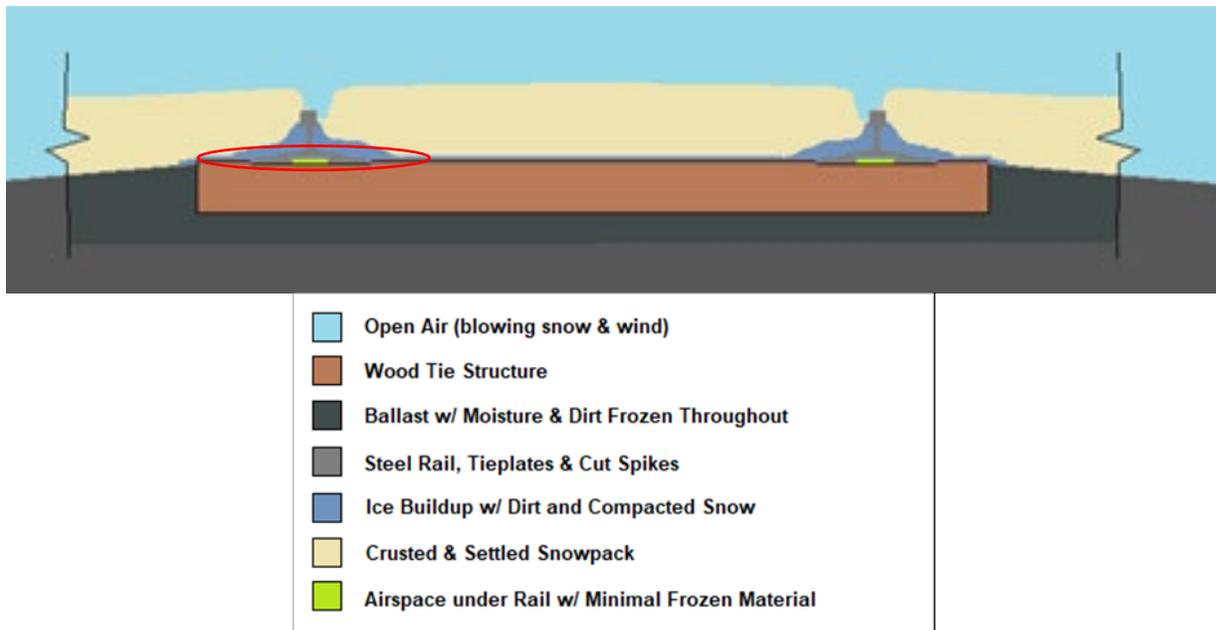


Figure 4. Track conditions of the grade crossing at 46.2802042, -96.0668825

Minimum gap between tie plates and rails is expected for railroad tracks. However, for the one rail seat that was dug, a 0.2-inch gap was found between the bottom of the rail and tie plate (Figure 5), but there was no ice and dirt underneath the rail. Since the shoulder of the tie plate was 7/16 inch tall, the rail base was measured about halfway up the tie plate shoulder.



Figure 5. A 0.2-inch gap found at one rail seat

Portable track loading fixture (PTLF) measurements were taken on four ties, every third tie in that area (see Table 1). The load was applied on the rail web only. The gage only increased 1/32 or 1/16 inch for the four ties when a 9,000-pound gage widening load was applied. The track was very stable and strong with all the ice, frozen dirt and ballast surrounding it.

Table 1. PTLF Results (unit = inch)

Tie #	0 psi	4,000 lbs.	6,000 lbs.	9,000 lbs.	Re-zero
1 (about 17 ties away from grade crossing)	56 7/16	56 7/16	56 15/32	56 1/2	56 1/2
2 (about 14 ties away from grade crossing)	56 11/16	56 23/32	56 3/4	56 3/4	56 3/4
3 (about 11 ties away from grade crossing)	56 23/32	56 3/4	56 3/4	56 3/4	56 3/4
4 (about 8 ties away from grade crossing)	56 23/32	56 3/4	56 3/4	56 3/4	56 3/4

Another grade crossing (46.3381161, -96.1666634) outside the town was inspected on the second day. This grade crossing was on a tangent track as well and had better track conditions (relatively new ties, clean ballast, and good drainage). The snow and ice were removed relatively easily compared to the previous location, and about twelve rail seats were exposed and inspected. High spikes (~0.5 inch) were found but most tie plates did not have a gap at the bottom of the rail. Only one tie plate had about a 0.1-inch gap between the tie plate and rail, but no ice was built up in the gap. Ice was observed as having built up between the high spikes and the top surface of tie plates (Figure 6). This observation is informative because it confirmed that ice is able to build up in gaps in a fastening system if certain conditions were met. While the exact mechanism is still unknown, one hypothesis as informed by the OTVR track manager, is that ice is able to be built up in the gaps in the fastening system if melted snow and ice are able to drip down under the rail seat and refreeze.



Figure 6. Grade Crossing at 46.3381161, -96.1666634

2.2 Trip 2: Canadian Pacific, White River, ON, Canada (February 28 – March 2, 2022)

During the second trip, the MxV Rail team visited multiple locations on CP tracks in the White River and Heron Bay Subdivisions of Ontario, Canada to observe tie plate icing. Out of eight inspected locations, only one location had tie plate icing where the rail was lifted above the tie plate shoulder. Other locations generally showed minimal icing.

The problematic location generally had worse track conditions compared to the other locations without tie plate icing. As shown in Figure 7, the location where tie plate icing was found had missing anchors, degraded wood ties, and fouled ballast. The gaps between rails and tie plates were measured with a ruler and are listed in Table 2. The bottom of the rail at several ties (Tie# 4, 5, 6, 7) was above the tie plate shoulder on both sides. However, since the cut spikes in these locations were still in place, the track gage strength was not reduced.

Table 2. Measurement of gaps between rails and tie plates

Tie	Field Side of Rail (inch)	Gage Side of Rail (inch)
1	12/32	13/32
2	11/32	15/32
3	10/32	14/32
4	16/32	21/32
5	17/32	20/32
6	19/32	23/32
7	17/32	17/32
8	13/32	14/32

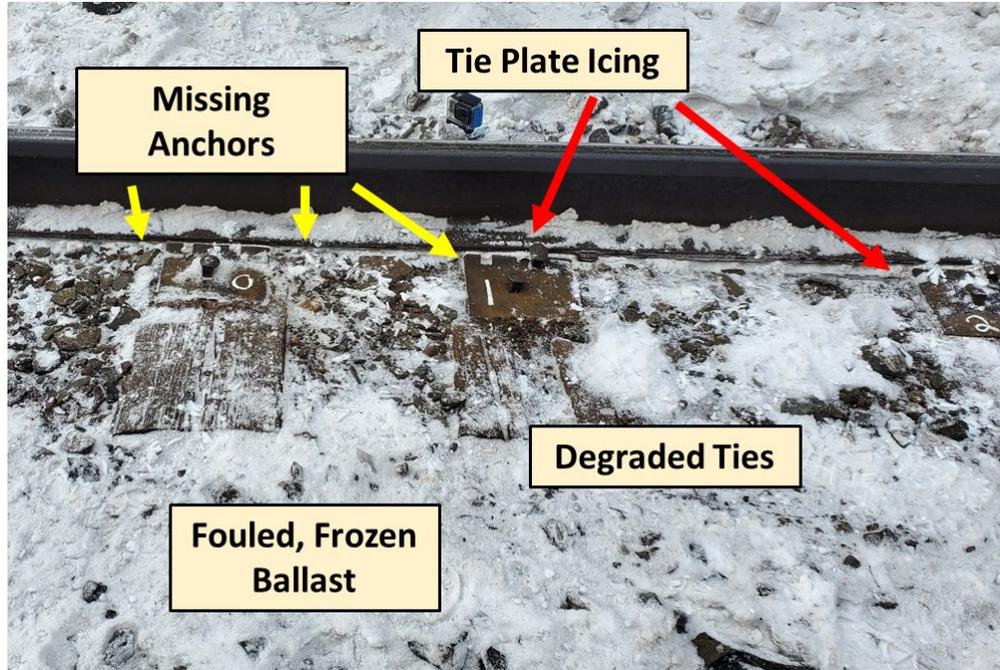
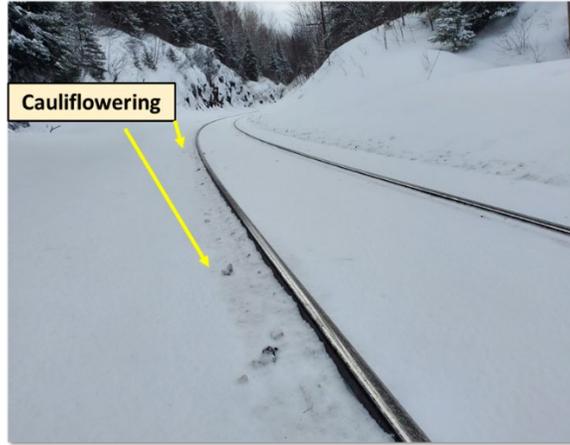


Figure 7. Location with tie plate icing in Heron Bay Sub

Based on CP's experience, problematic locations are often associated with the following conditions:

- Snow covered
- Higher-degree curves
- High RNT (rail neutral temperature)
- Poor anchoring
- Tie degradation
- Fouled ballast

CP also mentioned that it does not need very low temperatures or heavy snowfalls to form tie plate icing. The hypothesis is that snow gets trapped in any gaps between the rail and the tie plate. Rail movement, especially on the outside rail in curves, packs down snow/ice in layers, until the rail is jacked above the tie plate shoulder. When the track is covered with snow, it is difficult to identify problematic locations. One possible indication of tie plate icing that can be seen during a visual inspection is called “cauliflowering” (Figure 8), i.e., cracked/moved snow or ice near the rail base, indicating rail movement.



(a)



(b)

Figure 8. “Cauliflowering” of snow/ice near rail: (a) entire curve; (b) close up view

2.3 Trip 3: Canadian National, Winnipeg, MB, Canada (March 7-10, 2022)

On the third trip, the team inspected multiple CN track locations in the River Subdivision near Winnipeg, Manitoba, Canada. Out of the eight inspected locations, no ice jacking (CN’s term for tie plate icing) was observed. The tracks were frozen and did not show any track gage strength reduction.



Figure 9. CN River Subdivision

Representatives from CN stated that the ice jacking issue is possible any time snow is around the base of the rail and tie plates and can occur anywhere the rail is not tightly seated in the tie plate. Problematic locations are often associated with snow cover, high-degree curves, and poor ties and fasteners conditions. These representatives also mentioned “black marbling” (Figure 10) as an indicator of potential areas of ice jacking. This indicator also shows the rail movement around the rail base area.

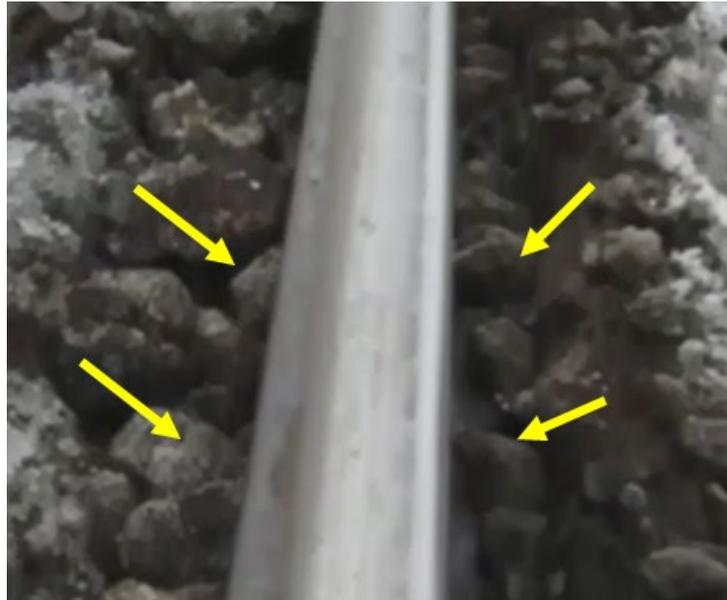


Figure 10. “Black Marbling”

2.4 Summary of Field Investigations

From the experience of three field investigations, it is difficult to identify the problem with snow cover. Also, tie plate icing locations often move around, depending on where the ties are in the tie degradation cycle. Locating a spot of ice jacking relies on the the experience of the railroad employees, but there is no guarantee for a method that will identify tie plate icing. It is believed that tie plate icing is caused by a combined effect of track conditions and weather conditions. The track conditions will cause the rail not tightly seated on the tie plate and the weather conditions will fill the gap with snow or ice. The following list presents several factors that can cause tie plate icing. It should be noted that these factors are often found when tie plate icing occurs, however, they are not guaranteed to cause tie plate icing.

Track conditions:

- Tie degradation, especially wood ties with cut spikes
- Fastener deterioration (high spike, broken spikes, etc.)
- Poor drainage and ballast fouling
- High rail neutral temperature (RNT)
- Hanging ties
- Rail pumping

Weather conditions:

- Cold weather conditions
- Rail jacked by snow: Moveable snow from train passage
- Rail jacked by ice: Freeze-thaw of ice/snow

Based on the discussion with railroads, there are (at least) two conditions that could cause tie plate icing: rail jacked by snow and rail jacked by ice. The first condition is created by snow getting blown against the bottom of the rail and then becomes packed layer by layer to jack up the rail. The second condition is caused by weather conditions that create freeze-thaw cycles where snow/ice melts and becomes trapped in the gap between the bottom of the rail and tie plate and freezes again. Ice jacking is often associated with poor drainage. Figure 11 illustrates the two possible conditions for tie plate icing.

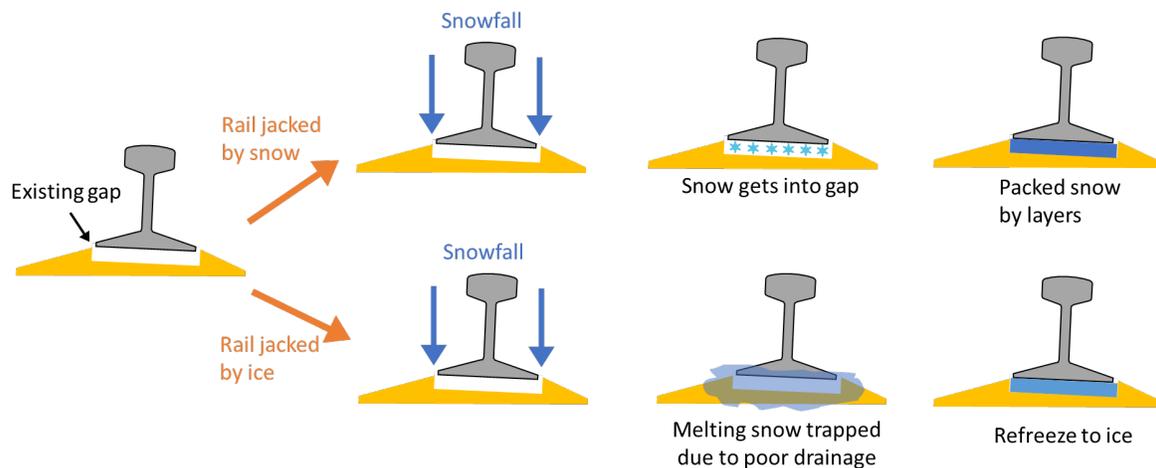


Figure 11. Two conditions for tie plate icing

Remediation methods are generally known but are difficult to apply on an economical basis. The following remediation actions have been taken by the three railroads:

- Production actions: Increase tie renewal cycle
- Spot component replacement: Use elastic fasteners, curve blocks, etc.
- Spot surfacing: Tighten up track geometry
- Ice removal: Manual removal or melting with snake rope
- Increase inspection: Focus on areas prone to ice jacking or areas with snow or ice
- Spot fastener and ballast maintenance: reset high spikes and enhance ballast drainage

3.0 PRELIMINARY MODEL FOR TIE PLATE ICING

A FE model has been established to further understand the tie plate icing issue. The model is capable of simulating a detailed rail-fastener-tie system with ballast support as shown in Figure 12, and it will mainly be used to evaluate the track gage strength when tie plate icing occurs. By simulating various track situations, some of which are not efficient and economical to obtain in the field, the model could provide a quick and useful understanding of how different variables

affect the track gage strength. However, the model is only used for mechanical simulation, and therefore, it is not able to simulate the temperature change and freeze-thaw cycle of snow/ice. The following are variables that can be included/quantified in the model:

- Tie conditions: Hanging tie, degraded tie (low tie modulus)
- Fastening conditions: Broken/missing spikes
- Tie plate icing: Adjust the distance the rail is lifted above the tie plate
- Rail neutral temperature and curvature: Apply longitudinal and lateral rail forces

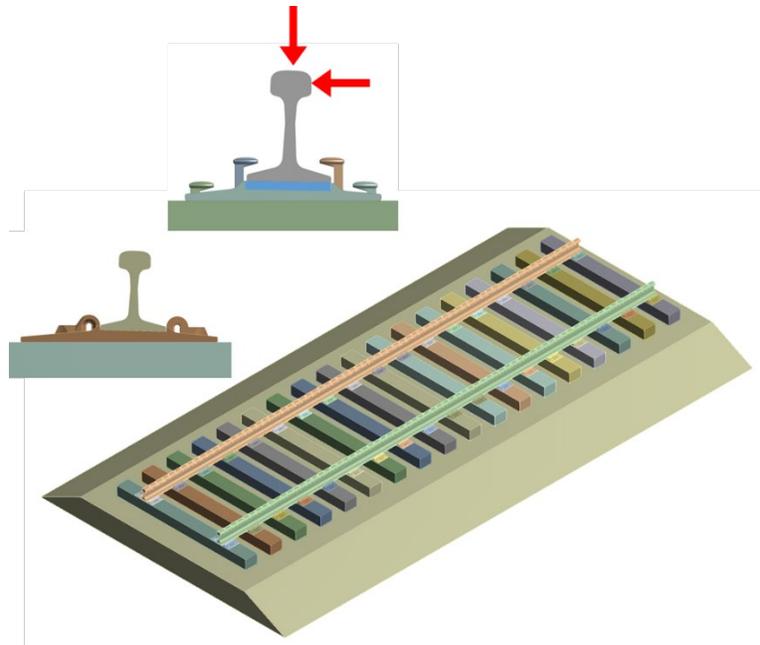


Figure 12. FE model for tie plate icing

Future work will include model validation using laboratory testing that will be proposed in the later sections. Then, a comprehensive modeling effort will be conducted to assess the influence of tie plate icing on track performance, mainly on gage strength. The model aims to answer the following questions:

- How will gage strength change when tie plate icing occurs?
- How many consecutive tie plates with tie plate icing would bring a safety concern?
- What effect do tie conditions (degraded tie) and fastening conditions (broken/missing spikes) have on gage strength?
- How will the distance the rail is lifted above the tie plate affect gage strength?
- How will RNT and curvature affect gage widening?

4.0 LABORATORY TEST PLAN FOR TIE PLATE ICING STUDY

The main purpose of the laboratory test is to validate the computer model. The test will require the creation of a short track panel with wood ties. Shims will be used to simulate the occurrence

of tie plate icing. Lateral track gage strength will be quantified by PTLF. The following test cases will be set up in the laboratory:

- Adjusting the shim thickness to simulate different severities of tie plate icing.
- Installing shims on multiple ties to simulate tie plate icing on consecutive ties.
- Removing cut spikes to simulate broken/missing spikes. Different spiking patterns will be used to include various situations.
- Applying longitudinal forces to simulate thermal forces induced in rails.

Once the gage strength from the above laboratory cases matches the modeling results, the model considered to be verified. It is important to verify the model before expanding the modeling effort to other cases.

This laboratory test plan is still in its initial stage. A survey of railroad practices was recommended by Transport Canada Project Steering Committee. A detailed test plan will be discussed with the committee and will be prepared after obtaining inputs from more railroads based on the survey.

5.0 SUMMARY AND FUTURE RESEARCH RECOMMENDATIONS

In this phase of research, MxV Rail performed field inspections of locations for three railroads to investigate the tie plate icing issue. Additionally, a preliminary computer simulation model was built, and a conceptual laboratory test plan was prepared for future work on the tie plate icing study.

The field investigations were performed at sites on three different railroads: Genesee & Wyoming, Fergus Falls, Minnesota, USA; Canadian Pacific (CP), White River, Ontario, Canada; and Canadian National (CN), Winnipeg, Manitoba, Canada. Based on what was experienced during these field investigations, it was difficult to identify possible ice jacking locations with snow cover. Finding a potential ice jacking location relied on the experience of the railroad employees but there was no guarantee that a location could be identified. The following include the field indications for identification:

- Track condition (cant, gage, general tie condition).
- Historical knowledge from the local crew.
- “Black marbling”/“cauliflowering.”

Track conditions and weather conditions were found to act jointly to cause tie plate icing. The areas of concern were typically on tracks with wood ties and cut spikes, where the rail is not tightly seated in the tie plate, allowing snow or ice to accumulate between the bottom of the rail and tie plate. Two conditions that cause rail lift above the tie plate shoulder were identified as follows: jacked by snow (“snow jacking”) and jacked by ice (“ice jacking”). “Snow jacking” occurs when snow gets pushed to the bottom of the rail and packed in layers by train loads. “Ice jacking” occurs when weather conditions allow freeze-thaw cycles to occur. This cycle happens

snow/ice melts and gets trapped in the gap between the bottom of the rail and tie plate and becomes frozen again.

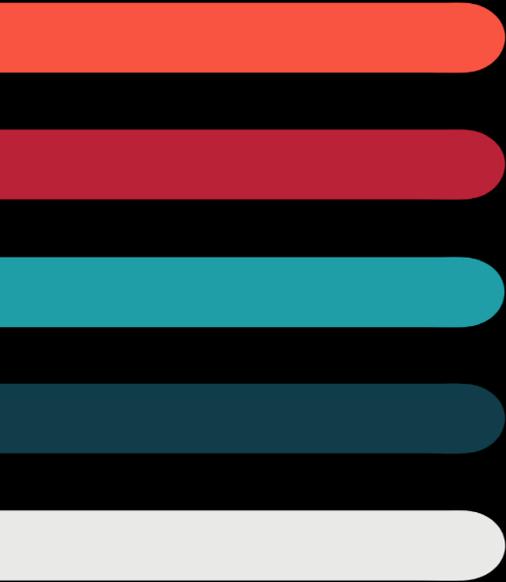
Based on the experience of the three railroads, the remediation actions included manual removal of ice or melting with snake rope, replacement of degraded ties and fasteners, improved ballast drainage, and maintenance to tighten up geometry.

Future work will include a survey of railroad practices of inspecting, identifying, and remediating tie plate icing. Both the comprehensive modeling effort and the laboratory testing proposed in this report will be performed under the guidance of the project steering committee. MxV Rail will work with Canadian railroads to identify and develop potential tie plate icing remediation methods to be evaluated in track.

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