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Too late snow wall removal as an enabler of rapid edge deformations - results from Aurora instrumented road sections on road E8 in Finland

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ABSTRACT: Since early spring 2018 Tampere University and Roadscanners Oy have conducted long term structural and functional monitoring of two road sections on road E8 in Muonio, Finnish Lapland. This monitoring has been part of the Aurora project, an open testing ecosystem of intelligent transport and infrastructure solutions launched by the Finnish Transport Infrastructure Agency (FTIA). One of the unique observations made based on monitoring the vertical strains of base course layer and the vertical displacement of road surface concerns abrupt frost heave that takes place in the upper part of pavement structure in late spring before the start of thawing period. The phenomenon coincides with the melting of snow next to road edge, which indicates that the source of water enabling this late spring frost heave is from the side of road, not through the deeply frozen structural layers below. The conclusion was verified by means of periodic GPR measurements applied in monitoring the water content of road structure. The above observation emphasizes the importance of early enough removal of snow walls from road shoulders as a means of limiting the edge deformation and rutting of road structures during the thawing phase of seasonal frost.

Keywords: Edge deformation, spring thaw, frost heave, snow wall, Aurora

1 INTRODUCTION

The effects of seasonal frost have for long time been acknowledged as one of the dominant reasons for road deterioration in the Northern regions (e.g. Kestler 2003). Especially harmful are the consequences of thaw weakening of road structure during the early phase of thawing when the melting ice lenses are increasing the water content of road structure, but there is still frozen and thus almost impermeable subgrade soil below (Saarenketo & Aho 2005). From road structure's point of view typical consequences of this bearing capacity loss are rapid rut development in unbound structural layers and accelerated fatigue in bound layers.

A less acknowledged phenomenon related to the very beginning of thawing period concerns frost heaves that take place near to the edge of road just before the actual thawing of road structure starts. According to the authors' understanding it is due to the melting water of snow infiltrating into the road structure via road shoulders due to cryo-suction in the unbound structural layers of road. As this results in an increase in the moisture content of base course layer during the critical time of early spring thaw, it is potentially a marked contributor to rut

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development in the upper part of road structure. Consequently, on areas with high snowfall a very critical issue is thus early enough removal of snow walls next to the road edge, since this is the most efficient action that can be taken to limit the amount of infiltrating water.

In connection with Aurora project, an open testing ecosystem of intelligent transport and infrastructure solutions launched by the Finnish Transport Infrastructure Agency (FTIA), Tampere University and Roadscanners Oy have jointly been monitoring the structural and functional condition of two extensively instrumented road sections on road E8 in Muonio, Finnish Lapland since late autumn 2017 (Kolisoja et al. 2019). The results of long-term monitoring have clearly indicated, to the knowledge of authors for the very first time in the world, this phenomenon of thawing time frost heave to take place in a measurable quantity. Furthermore, the monitoring results indicate an abrupt increase in base course rutting when this short-term frost heave settles. The actual monitoring results from Aurora instrumented road sections concerning this issue are presented in more detail in the following chapters.

2 MATERIALS AND METHODS

2.1 *Long-term structural monitoring of Aurora sites*

The Aurora monitoring sites are located on road E8, a couple of kilometers South from the village of Muonio, in Western Finnish Lapland. On the Aurora 1 site, located on a curve to the right in a place where nearby threes are providing some shadow when the sun is not shining very high, the thickness of structural layers is about 1.1 meters. The substructure of the Aurora 1 site consists of dense moraine with stones and boulders. Before the structural instrumentations were installed, existing asphalt concrete (AC) layer was removed from the site on an area of about 3 * 5 m^2. After the instrumentation the Aurora 1 site was overlain by about 120 mm of new AC that was installed in two layers. On the Aurora 2 site, located on a straight road section open for sunshine, the overall thickness of unbound structural layers resting on top of a sandy embankment is about 1.5 meters. In connection with the renovation works carried out on the Aurora 2 area in 2017 the old AC layer that was about 70 mm thick, was mix-milled with some added coarse grained aggregate and the existing unbound base course layer made of crushed rock. Finally, the road was overlain by 90 mm of new AC installed in two layers. Corresponding to the alignment of both sites the slope of road surface at Aurora 1 is one sided towards the installed instruments while at Aurora 2 it is two-sided as is typical for straight road sections.

Both the Aurora 1 and 2 sites are furnished with almost identical structural instrumentation setups, a sematic picture of which is shown in Figure 1. The instrumentations consist of the following instrument types and the numbers of installed transducers given in parentheses for the Aurora 1 and Aurora 2 sites, respectively:

- Displacement transducers monitoring the road surface deflection, RSDEF (0 + 3)
- Acceleration transducers monitoring the road surface deflection, RSACC (20 + 20)
- Horizontal strain transducers at the base of lower AC layer, ACSTR (5 + 6)
- Vertical pressure cells at two levels in unbound base course layer, BCPRE (8 + 8)
- Vertical strain transducers in the unbound base course layer, BCSTR (4 + 4)
- Percostation probes for monitoring dielectric value, electrical conductivity and temperature, PERCO (10 + 10)

A bit more detailed description of the instrumentations has been given earlier by Kolisoja et al. (2019). Regarding frost heaves taking place during early spring thaw the most interesting instruments are those measuring the vertical movements of road surface and the vertical strain of base course layer. Locations of these transducers in relation to the inner side of edge line have been summarized in Figure 2. At Aurora 1 site the typical driving lines of vehicles are somewhat closer to the road shoulder due to the right turning alignment of road.

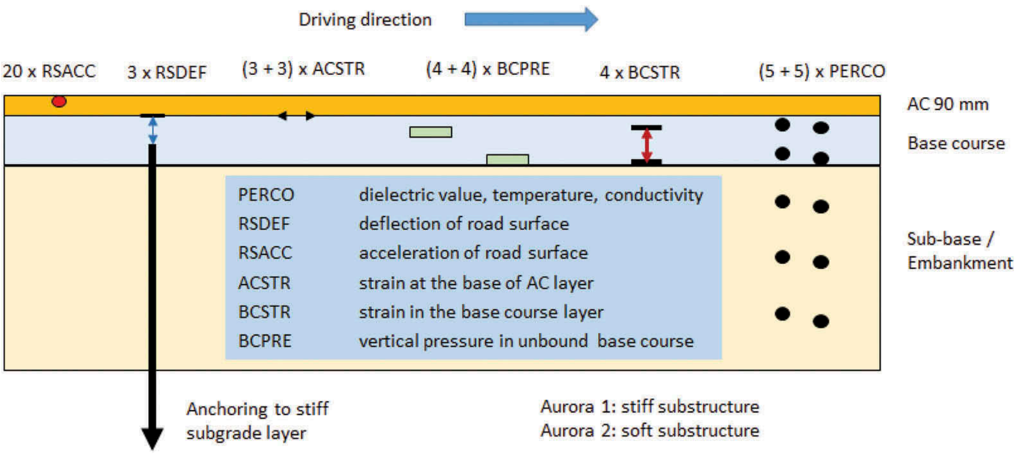

Figure 1. Sematic picture of structural instrumentations at Aurora 1 and 2 sites.

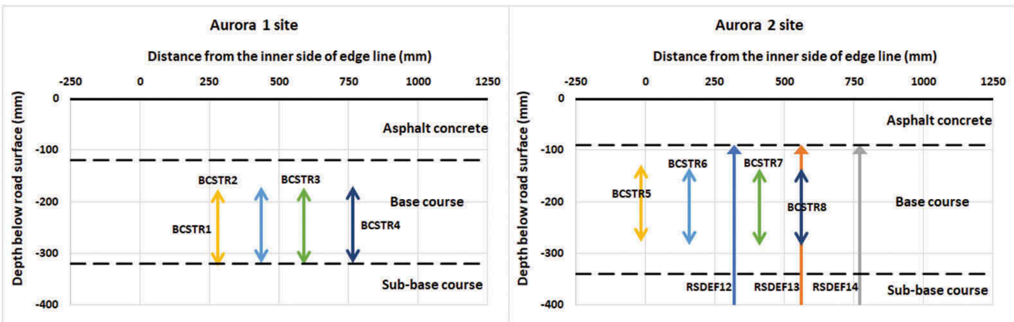

Figure 2. Distances of road surface deflection transducers and base course strain transducers from the inner side of edge line at Aurora 1 and 2 sites.

2.2 *Periodic on-surface monitoring of Aurora sites*

In 2018 and 2019 Aurora test sites were monitored using RDSV (Road Doctor Survey Van) equipped with Ground Penetrating Radar (GPR), laser scanner (lidar), 3D accelerometer technique and recording of digital videos from the road (Saarenketo 2017). In addition, GPR cross section surveys were conducted on both Aurora 1 and 2 sites. In 2018 both Aurora site road cross sections were monitored eight times starting from early February when road was frozen until June 18 when it had completely thawed. In 2019 surveys were conducted a few times during spring and summer. From the GPR data a special Moisture Damage Index (MDI), developed by Roadscanners Oy, was calculated (Arnold et al. 2017). In wintertime MDI indicates the amount of unfrozen water in frozen structure while in late spring high MDI values indicate high saturation degree in the material. In addition, laser scanner data was used to measure the exact shape of road surface, based on which rut depth maps and rut growth maps were derived. Figure 3 presents an example of the analyzed MDI values as well as rut depth and rut growth data at Aurora 1 site in 2018 and 2019. It indicates that moisture content was higher in late April 2019 than it was at the same time in 2018. It also shows fast rut growth, even more than 5 mm, in outer wheel paths especially in Southbound lane that loaded trucks are more often using.

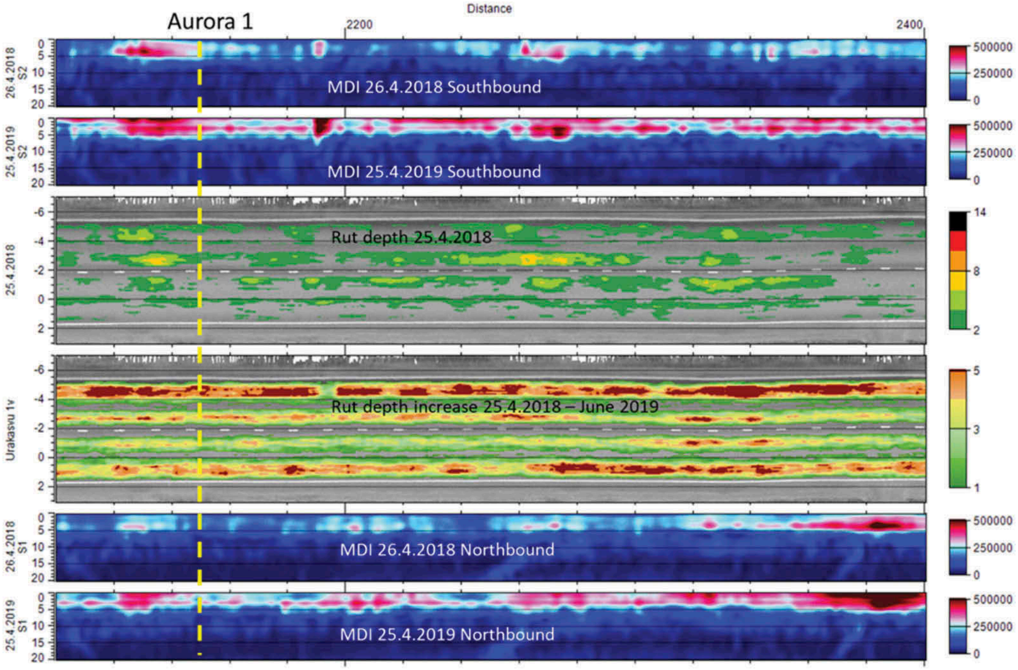

Figure 3. MDI values in April 2018 and 2019, rut depths in April 2018 and rut depth increase in between April 2018 and June 2019 at and around Aurora 1 site in Muonio.

3 MONITORING RESULTS

3.1 *Vertical displacements of road surface*

Long-term monitoring results regarding the vertical displacement of road surface are only available from Aurora 2 site since the installation of anchoring rods for displacement transducers was not successful at Aurora 1 site due to boulders in subgrade soil. At Aurora 2 site three displacement transducers were installed at distances from 0.32 to 0.77 m from the edge line and the respective changes in transducer readings in between the beginning of year 2018 to the late summer of 2019 have been shown Figure 4.

The results shown in Figure 4 indicate clearly that just before the thawing period of seasonal frost there has been a sudden heave of road surface of up to more than 5 mm. Correspondingly, in the very beginning of thawing period the road surface has settled from 7 to 9 mm in about one week, which means that most part of the overall frost heave on this site has taken place in the upper part of road structure also during the freezing period in the autumn (Figure 4).

In Figure 5 the thawing time road surface displacements at Aurora 2 site are show in cross sectional view for the first weeks of April 2018 and 2019. It seems obvious that at this site the thawing time frost heaves have been more pronounced towards the edge of road.

3.2 *Vertical deformations of base course layer*

3.2.1 *Aurora 1 site*

The vertical deformations of base course layer were monitored using four parallel displacements transducers on both Aurora sites. At Aurora 1 site transducers were located 0.28 m to 0.77 m from the edge line, while at Aurora 2 site the corresponding range was from -0.02 to 0.56 m (Figure 2). Right after installation the measurement range of base course strain

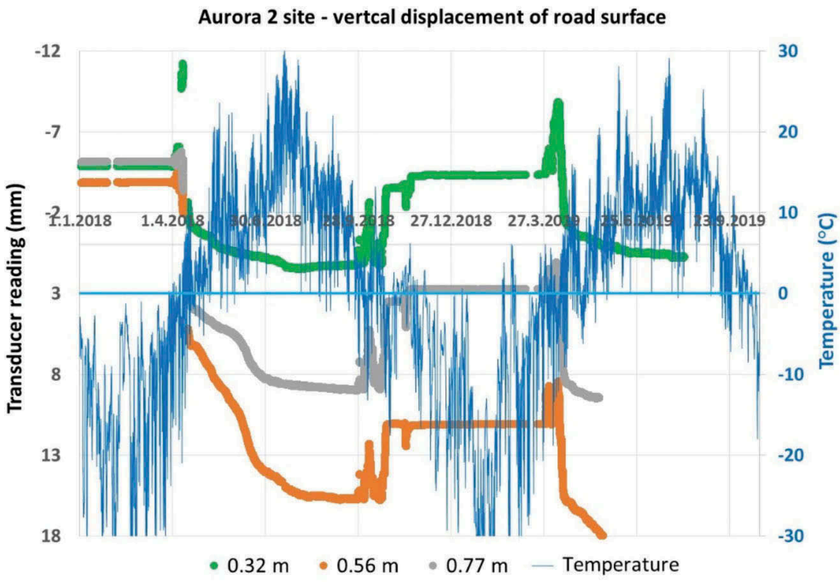

Figure 4. Vertical displacements of road surface at Aurora 2 site in between 1.1.2018 and summer 2019 and the respective air temperatures at Muonio weather station.

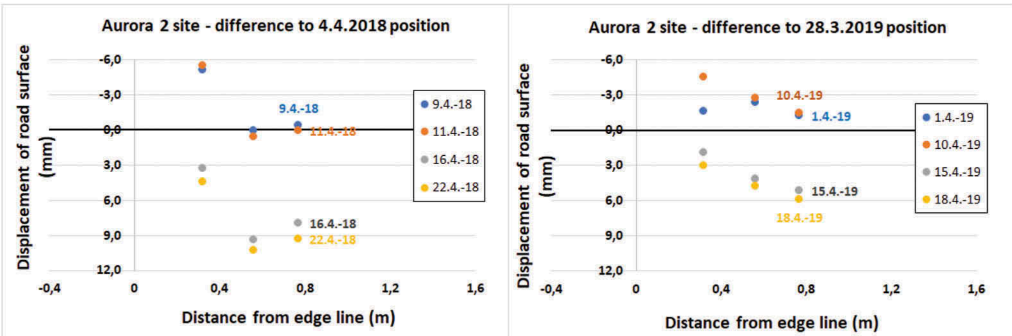

Figure 5. Vertical displacements of road surface in cross sectional view at Aurora 2 site in April 2018 and 2019.

transducers was adjusted to 150 mm, but due to permanent deformations that have taken place in the base course layer since then, the actual measurement range has slightly decreased. In Figures 6 to 9 all the transducer readings have been given directly in millimeters i.e. no conversion to strain values has been made.

Figure 6 indicates long-term vertical deformations that have taken place in the base course layer of Aurora 1 site in between 1.1.2018 and August 2019. Basically all the phenomena already seen in Figure 4 regarding the vertical displacement of road surface are reproduced here. An abrupt lengthening of measurement range similar to the very beginning of freezing period in the autumn 2018 is observed just preceding the start of thawing period both in early April 2018 and 2019. As thawing starts, both components of frost heave settle within in a few days.

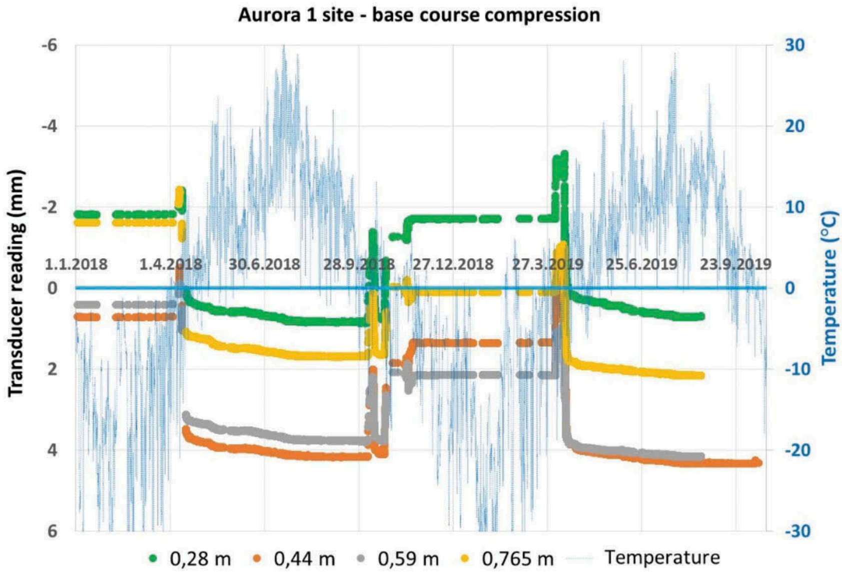

Figure 6. Vertical deformations of base course layer at Aurora 1 site in between 1.1.2018 and August 2019 and the respective air temperatures at Muonio weather station.

In Figure 7 the respective base course deformations taking place at Aurora 1 site during the first weeks of April are shown in cross sectional view. In comparison to the corresponding results from Aurora 2 (Figure 9) site as well as the vertical displacements measured from Aurora 2 site (Figure 5), the main difference is that the measured thawing time frost heaves are smaller in magnitude and also more evenly distributed in cross sectional direction. A possible explanation for this is that Aurora 1 site is located in a place less exposed to early springtime sunshine due to nearby trees than Aurora 2 site.

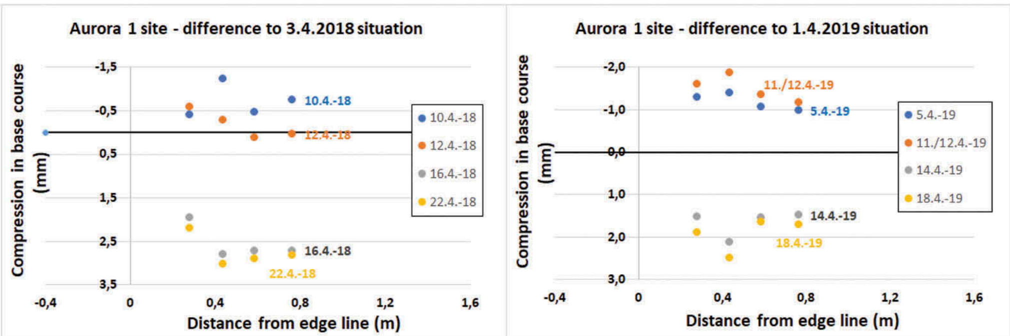

Figure 7. Vertical deformations of base course layer in cross sectional view at Aurora 1 site in April 2018 and 2019.

3.2.2 *Aurora 2 site*

Figure 8 presents the development of long-term vertical deformations in the base course layer of Aurora 2 site in between 1.1.2018 and September 2019. Again, an abrupt lengthening of the measurement range is preceding the start of thawing period both in April 2018 and 2019. Especially in April 2019 the magnitude of frost heave in base course layer is also clearly larger than that happening during the actual freezing of base course layer in autumn 2018.

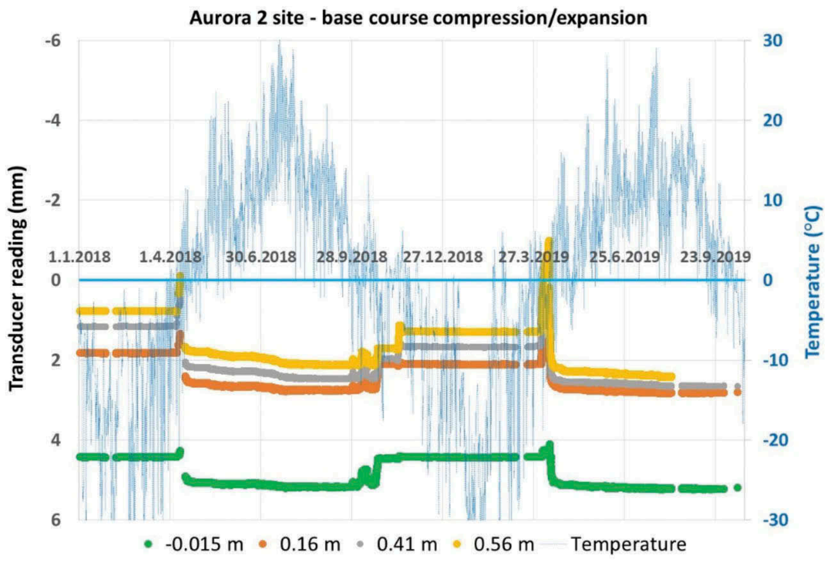

Figure 8. Vertical deformation of base course layer at Aurora 2 site in between 1.1.2018 and September 2019 and the respective air temperatures at Muonio weather station.

The cross-sectional distribution of frost heaves during the first weeks of April 2018 and 2019 corresponding to the results of Figure 8 are shown in Figure 9. It is noteworthy that the range of locations covered by base course strain transducers is now closer to the edge of AC layer than that of the displacement transducers measuring the road surface deflection (Figure 2), but still the result is somewhat contradictory to that of Figure 5. The frost heaves in base course seem to be the highest at a distance of about half a meter from the edge line, while at the edge line base course heave is hardly measurable. The reason for that has not been figured out by the time of writing this article.

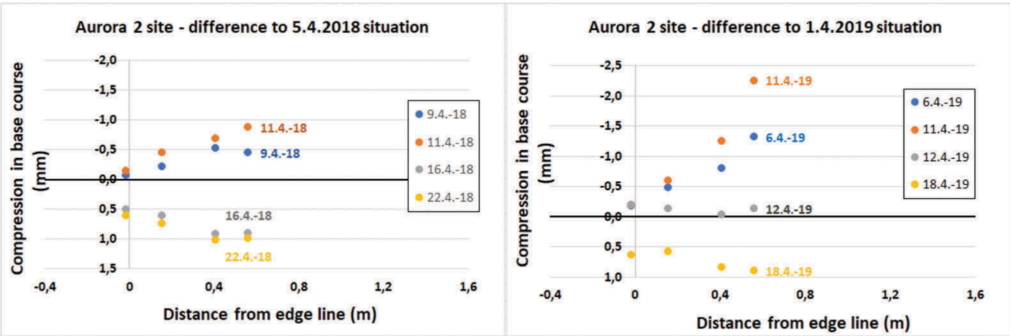

Figure 9. Vertical deformations of base course layer in cross sectional view at Aurora 2 site in April 2018 and 2019.

3.3 *GPR measurements*

The MDI values derived based on GPR measurements carried out at both road cross sections of the Aurora sites several times in 2018 are summarized in Figure 10 for the Aurora 1 site and in Figure 11 for the Aurora 2 site. As stated already above, in a frozen layer, i.e.

measurements made in February and March, red and black colours indicate high amount of unfrozen water while in an unfrozen layer they indicate high saturation ratio, respectively.

At the Aurora 1 site the highest MDI values both before and after the thawing of road structure are observed near to the edge of Southbound lane (Figure 10). This implies the existence of high cryo-suction values that would give a logical explanation for the movement of additional water into the base course layer and the appearance of consequent frost heave (Figures 6 and 7) as soon as melting water is available from snow walls next to the edge of road. After thawing, this additional water is keeping the moisture content of base course layer high until summer and making it thus susceptible to permanent deformations. As Figure 3 indicates permanent deformations determined using lidar measurements were observed to be most pronounced below the outer wheel path of Southbound lane where MDI values are also the highest.

At the Aurora 2 site MDI values are in general lower and also more evenly distributed (Figure 11) than at Aurora 1 site. A plausible reason for the lower MDI values and somewhat lower frost heaves at the Aurora 2 site is that the base course layer of the Aurora 2 site is more coarse grained and also contains some amount of bitumen as the result of aggregate addition and consequent mix-milling of the existing base course with the old AC layer during the rehabilitation works carried out on the site in 2017. In fact it seems that the highest MDI values after thawing of Aurora 2 site have been determined towards the center of road, which could imply to an unperfect AC layer joint in the middle of road, but this assumption has not been confirmed.

4 DISCUSSION

Long-term monitoring results both concerning road surface displacements and vertical deformations of base course layer at the Aurora 1 and 2 sites indicate undeniably that abrupt frost heaves take place just before the thawing of seasonal frost starts, in Western Lapland typically in early April. According to the presented monitoring results the magnitude of these

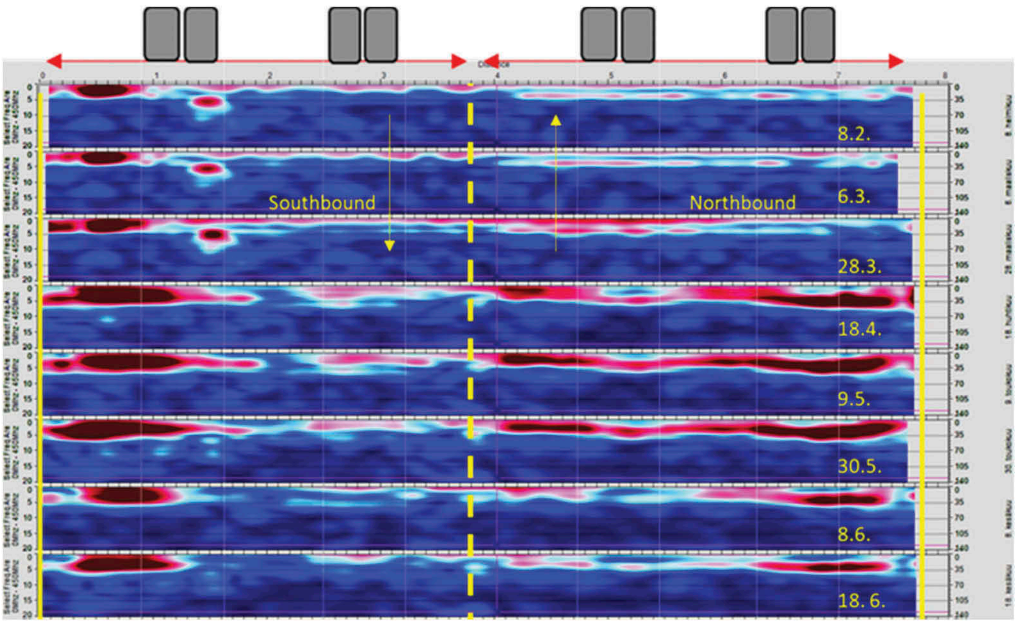

Figure 10. MDI values at the Aurora 1 site cross section in 2018. Red and black colors indicate high values of moisture content.

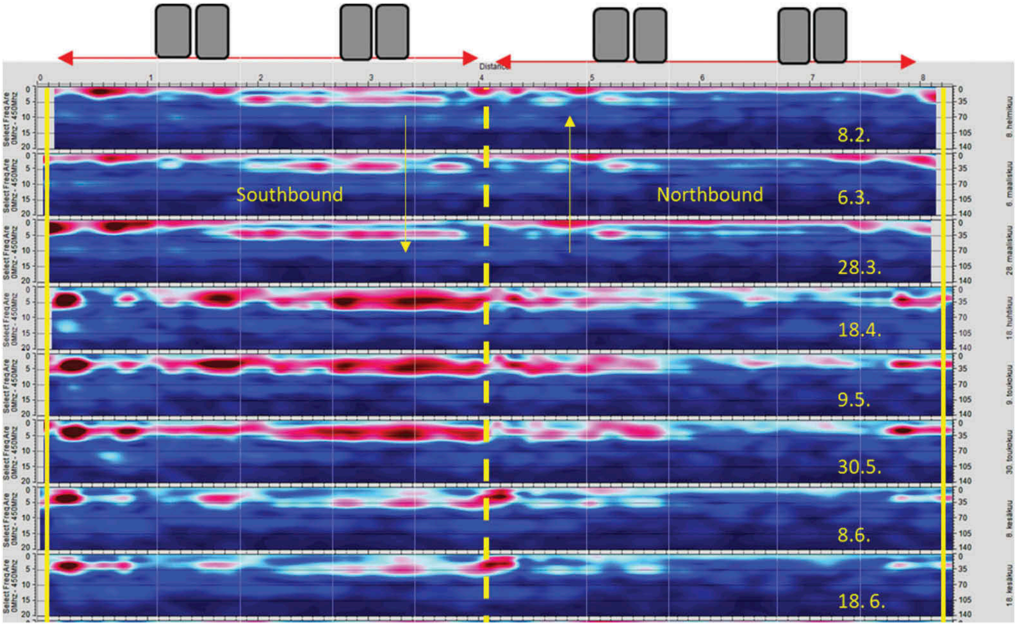

Figure 11. MDI values at the Aurora 2 site cross section in 2018. Red and black colors indicate high values of moisture content.

springtime frost heaves has been even exceeding frost heaves developing in the autumn when the monitoring sections have been freezing originally. The explanation for this phenomenon is believed to be so called tertiary frost heave, a concept originally suggested by Tommy Edeskär (2018) in a frost symposium held in Luleå. According to the concept, available water from the edge of road, typically originating from the melting of snow walls next to the road, moves inside to road structure driven by cryo-suction prevailing in the structural layers of frozen road.

The most important practical consequence of the observed phenomenon is that moisture content in the upper part of road structure increases markedly during the critical time when the thawing of frost starts from the top of road. This makes road structure susceptible to the rapid development of permanent deformations that is exactly what has happened especially at the Aurora 1 site (Figure 3) in a time period of only one and a half years after the installation of a new AC overlay. Correspondingly, the most efficient – but at the same time very inexpensive - countermeasure to avoid this detrimental process is early enough removal of the snow walls from the edges of road.

5 SUMMARY

In this paper monitoring results from two comprehensively instrumented road sites located at E8 in Muonio, Western Finnish Lapland, were presented. Based on those results the following conclusions could be drawn:

- Vertical displacements of road surface at one of the sites and vertical deformations at both of the sites have been monitored during two thawing periods from the beginning of 2018 to the summer of 2019.
- Marked frost heaves have been observed to take place in the upper part of road structure at the very beginning of thawing period. This phenomenon, also called as tertiary frost

- heave, is assumed to be caused by the melting water of snow walls that is drawn into the base course layer of road by cryo-suction effect.
- The MDI values derived based on GPR measurements strongly support this assumption.
- Rapid rut development has been recorded at the points were this tertiary frost heave phenomenon has been observed to take place.
- Early enough removal of snow walls next to road shoulders is evidently the most important measure to counteract rapid rut development caused by thawing time frost heave.

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