Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0907

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Open structural monitoring data from two extensively instrumented road sections – case Aurora

Données de surveillance structurelle ouverte de deux sections de route largement instrumentées - cas Aurora

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ABSTRACT: In 2017, the Finnish Transport Agency (FTA) launched an open testing ecosystem of intelligent transport and infrastructure solutions, known as Aurora. The Aurora test area consists of an approximately 10 km section of main highway E8 South from the village of Muonio, Finnish Lapland. Regarding road infrastructure, the core of the testing ecosystem consists of two extensively instrumented road sections, one of which is located on a stiff substructure area and the other on a softer substructure area. Commissioned by the FTA, the structural instrumentation of Aurora monitoring sections was accomplished jointly by Tampere University of Technology (TUT) and Roadscanners Ltd (RS). Instrumentations installed in these sections enable both continuous monitoring of structural condition and structural responses during vehicle overpasses. In addition, a nearby concrete slab bridge furnished with a Weigh-In-Motion (WIM) system enables monitoring of the vehicle masses. A unique feature of the monitoring systems described in more detail in this article is that all the monitoring results to be collected during a period of three years are made publicly available via the FTA website as open data.

RÉSUMÉ: En 2017, l'agence finlandaise des transports (FTA) a lancé un écosystème de tests des systèmes de transport intelligents et de solutions d'infrastructure, baptisé Aurora. La zone d'essai Aurora consiste en une section d'environ 10 km de l'autoroute principale E8 située au sud du village de Muonio, en Laponie finlandaise. En ce qui concerne les infrastructures routières, l'écosystème d'essais est constitué de deux tronçons routiers dotés de nombreux instruments, l'un se trouvant sur une infrastructure rigide et l'autre sur une infrastructure plus souple. Commandée par l'agence finlandaise des transports, l'instrumentation structurelle des sections de tests Aurora a été réalisée conjointement par l'Université de technologie de Tampere (TUT) et Roadscanners Ltd (RS). Les instruments de mesure installés dans ces sections permettent à la fois de surveiller en permanence l'état de la structure et la réponse de cette dernière aux passages des véhicules. De plus, un pont en béton armé équipé d'un système de pesée en marche (SPM) permet de contrôler le poids des véhicules. Une caractéristique unique des systèmes de surveillance décrits plus en détail dans cet article est que tous les résultats qui seront collectés au cours d'une période de trois ans seront rendus publics via le site web de l'agence finlandaise des transports en données ouvertes.

Keywords: monitoring, structural condition, structural response, weigh-in-motion, open data, Aurora

1 INTRODUCTION

Road infrastructures are facing a number of on-going trends that are challenging their condition and service life. These include:

- Progress of climate change that results in increasing amounts of rainfall, more frequently appearing extreme heat waves and in the Northern regions an increasing number of freeze-thaw cycles per year (Trenberth 2011).
- Introduction of super heavy trucks when the CO2 emissions are aimed to be reduced by increasing the efficiency of road transports.
- Transition from dual wheels to super single tires that are known to be much more harmful to the road infrastructure (Kolisoja et al. 2015).
- Forthcoming introduction of autonomous cars and trucks that can in worst case result in dramatic reduction of wheel path wander in between different vehicles.
- Continuous shortage of resources allocated to road maintenance.

In the long run, the only thinkable solution in tackling these challenges is in the overall change of practices in the road infrastructures maintenance. From reactive maintenance i.e. from repearing of already broken down structures a transition must be made to a proactive maintenance in which the initiating damages are recognized and repaired at an early stage before the required renovation actions are not very extensive and expensive (Tapio et al. 2016).

An essential prerequisite for this transition is, however, that more advanced technologies are applied in surveying the condition of existing roads. Equally important is that a better understanding on the mechanical behavior of actual road structures and their deterioration mechanisms in the prevailing conditions is developed. One indispensable tool in accumulation of this understanding is long term in-situ monitoring of existing road structures while they are exposed to real traffic loading and variable weather conditions. This paper presents an example of this type of monitoring arrangement - case Aurora - accomplished jointly by the Tampere University of Technology and Roadscanners Ltd in the village of Muonio in the Western part of Finnish Lapland in 2017.

2 INSTALLED MONITORING SYSTEMS

2.1 Instrumentation sites

The installed monitoring systems include two road sections, Aurora 1 and 2, both located on the main road E8 about four kilometers South from the center of the village of Muonio and a Weigh-in-Motion (WIM) station installed in a concrete slab bridge in the North side of the village. All of these three instrumentation sites are components of the Aurora test area, a testing ecosystem of intelligent transport and infrastructure solutions in Nordic conditions launched by the Finnish Transport Agency, FTA (2018).

On the Aurora 1 test site, the thickness of structural layers is about 1.1. meters. The substructure of the Aurora 1 site is stiff, and it consists mainly of dense moraine with a number of stones and boulders. Before the structural instrumentations were installed, existing asphalt concrete (AC) layer was removed from the site. After the instrumentation the site was overlain by about 120 mm of new AC material that was installed in two layers.

On the Aurora 2 test site, the overall thickness of unbound structural layers resting on top of a sandy embankment is about 1.5 meters. Together with a sandy subgrade it constitutes a substructure with clearly lower stiffness than that of the Aurora 1 test site. In terms of Base Curvature Index, BCI, the difference in road surface deflections at the distances of 900 mm and 1200 mm from the center of the Falling Weight Dephlectometer loading plate, the determined values after the installation of measuring instruments were about 20 for the Aurora 1 test site and 35 for the Aurora 2 test site, respectively. In connection with the renovation works carried out on the Aurora 2 area in 2017

the old AC layer of about 70 mm thick was mix-milled with the existing unbound base course layer made of crushed rock. Finally the road structure was overlain by 90 mm of new AC installed in two layers.

2.2 *Structural instrumentations*

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

- Displacement transducers monitoring the road surface deflection (0 + 3)
- Acceleration transducers monitoring also the road surface deflection (20 + 20)
- Horizontal strain transducers at the base of lower AC layer (5 + 6)
- Vertical pressure cells at two levels in the unbound base course layer (8 + 8)
- Vertical strain transducers in the unbound base course layer (4 + 4)

All the structural monitoring instruments on both of the sites have been installed under the outer wheel path of the lane from North to South. The parallel instruments are installed at a spacing of 150 to 200 mm in cross-sectional direction of road to enable obtaining of a more complete picture of the 3D distribution of structural responses caused by vehicle loadings. The only exception is acceleration transducers that have been installed in two rows with an instrument to instrument spacing of only 100 mm.

Five Percostation® probes monitoring long term changes in dielectric value, electrical conductivity and temperature were installed at different depths varying from 0.15 m to 1.10 m below the road surface. Five Digipercostation® probes that enable also monitoring of short term changes in the dielectric value during vehicle overpasses were installed parallel to the traditional type of probes up to the depth of 1.1 m.

2.3 *On-surface instrumentation*

In addition to the structural instrumentations, there are also other on-surface monitoring instruments that enable recognition of the passing by vehicles and their axle loads. These include:

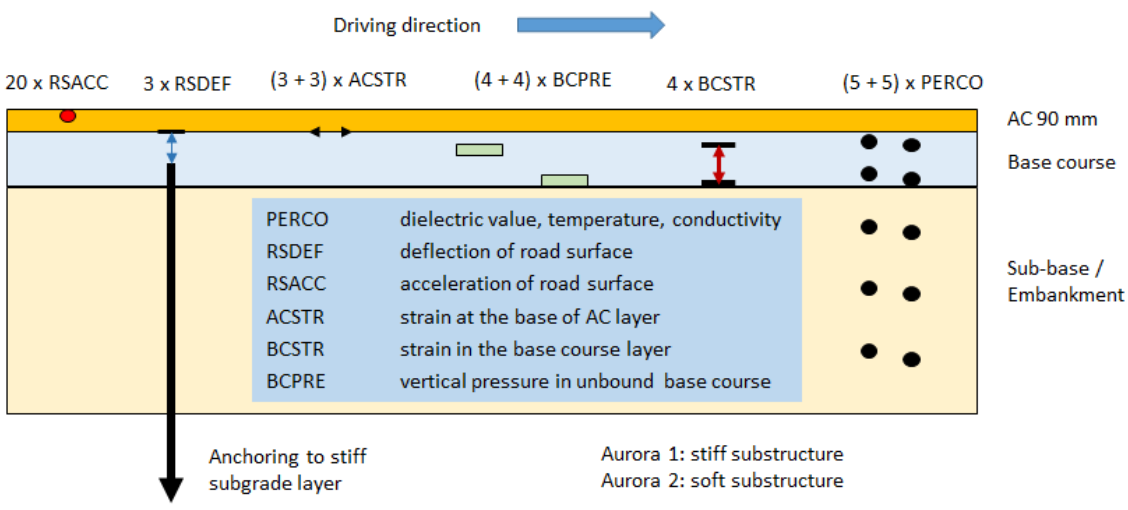

Figure 1. Scematic picture of structural instrumentations at Aurora 1 and 2 test sites.

- Laser scanners that are recognizing both the speed, dimension and shape of a passing by vehicle as well as the position of vehicle's outer wheel path in terms of distance to the outer surface of vehicle's tires.
- On the Aurora 2 test site, a thermal camera that records the road surface temperature especially with the aim of recognizing the possible pumping of water from the embankment and subgrade soil into the road structure during spring thaw conditions.

2.4 Weigh-in-Motion system

As mentioned above, a Weigh-in-Motion (WIM) system has been installed in a concrete slab bridge a few kilometers North form Aurora 1 and 2 sites. It enables monitoring of:
- Number and type of heavy vehicles
- Vehicle speed
- Number of axles and distances between axles in each heavy vehicle
- Axle and axle group weights as well as the total weight of a passing over vehicle

2.5 Data aquisition systems

All of the data acquisition systems recording the results from the monitoring instruments described above have been designed to operate stand-alone i.e. data acquisition is triggered automatically for a certain time by each passing by heavy vehicle and, therefore, no operating personal are needed on site.

The sampling rate used in connection with structural response measurements is 1 kHz i.e. thousand samples per second and per channel. The only exception are Digipercostation® probes in which the sampling rate is 60 readings per second per channel.

The monitoring data from all of the structural response measurements is transferred daily into a server of the Finnish Transport Agency from where it can be uploaded as open access data (see Chapter 4). In the case of WIM and laser scanner measurements, however, only the processed data is available at the FTA server.

3 EXAMPES OF MONITORING RESULTS

3.1 Structural response measurements

Given that the monitoring systems are built to operate stand-alone, a lot of heavy vehicle overpasses can be easily recorded. On the other hand, a drawback is that the vehicle types must be recognized based on the monitored data and then connected to the information on vehicle weights available from the WIM-station. An example of the utilization of this type of massively collected monitoring data is given hereafter.

One frequent type of heavy vehicle traveling from North to South via highway E8 is a semitrailer truck transporting fish from Norway to Finland. These trucks typically weigh about 40 to 50 tons and have an 1 + 2 axle truck pulling a trailer with three axles. Figure 2 presents a summary of the measured road surface deflections at Aurora 2 test site caused by the steering axles of these "fish trucks" during a time period from the 19th of April to the 24th of April 2018. At that time the road structure had thawed up to the depth of about one meter (Figure 8).

When the recorded results are plotted as a function of the distance between the transducer in question and the location of outer wheel path of the vehicle, as has been made in Figure 2, it is obvious that all the parallel instruments have been producing quite nicely identical results. When analyzing the results shown in Figure 2 it is important to note that the actual weights of the steering axles of these trucks recorded at the WIM-station varied from 65 kN to 93 kN. Therefore, a certain amount of scatter in the results is inherent. In connection with specific loading tests carried out using a single truck that was passing over the site repeatedly, the scatter in the results was naturally smaller.

Corresponding results recorded during the overpasses of the same group of vehicles as in Figure 2 is given for vertical pressure at the depth of 180 mm below the road surface in Figure 3,

vertical pressure at the depth of 280 mm in Figure 4, vertical compression of the unbound base course layer in Figure 5, horizontal strain at the base of AC layer in the longitudinal direction of road in Figure 6 and horizontal strain in the transversal direction of road in Figure 7.

As Figure 2 indicates, the peak values of road surface deflection have been typically of the order of 0.4 mm and in the cross-sectional direction of road they have been decreasing down to about 0.1 mm at a distance of half a meter from the located position of the wheel path.

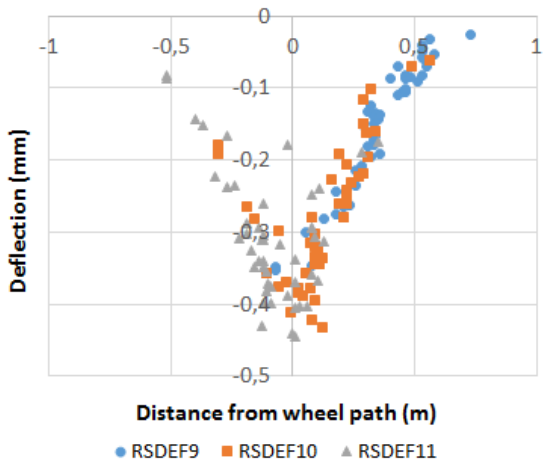

Figure 2. Road surface deflections measured with three parallel displacement transducers at Aurora 2 test site.

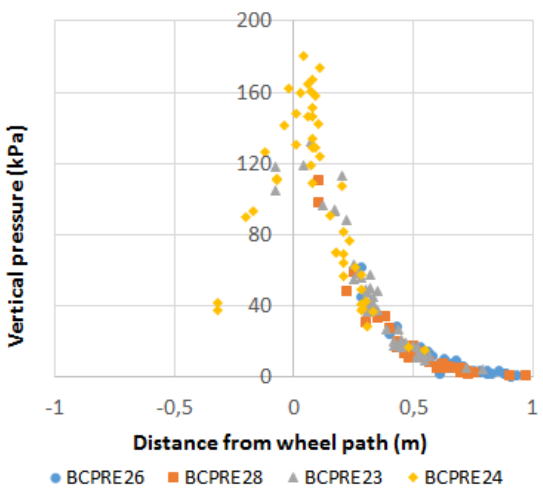

Figure 3. Vertical pressures measured with four parallel pressure cells at a depth of 180 mm at Aurora 2 test site.

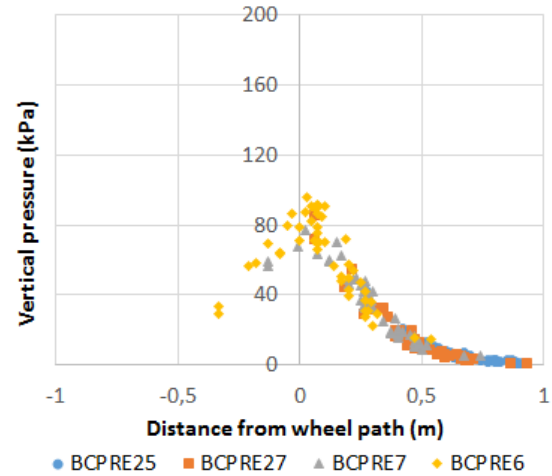

Figure 4. Vertical pressures measured with four parallel pressure cells at a depth of 280 mm at Aurora 2 test site.

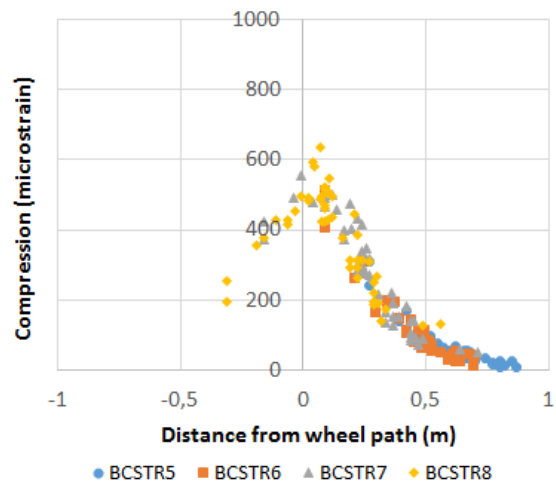

Figure 5. Vertical compression of unbound base course layer measured with four parallel strain transducers at Aurora 2 test site.

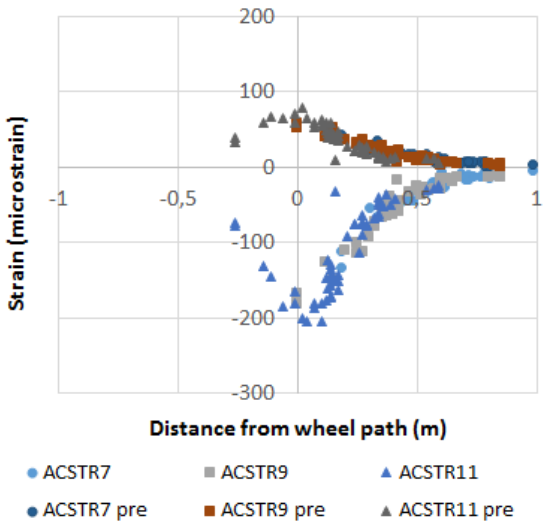

Figure 6. Horizontal strain at the base of AC layer in longitudinal direction measured with three parallel strain transducers at Aurora 2 test site.

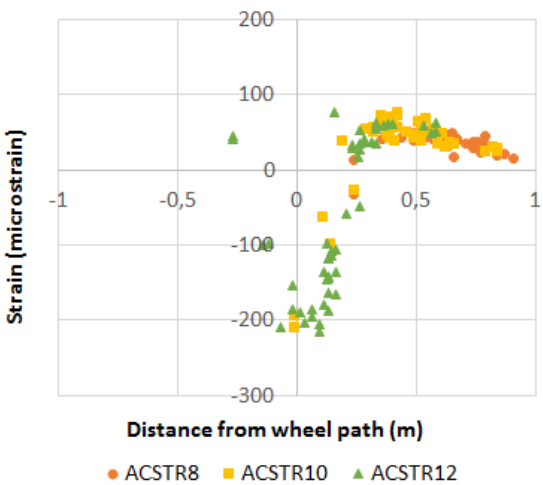

Figure 7. Horizontal strain at the base of AC layer in transversal direction measured with three parallel strain transducers at Aurora 2 test site.

The respective peak values determined for the vertical pressure in the unbound base course at a depth of 180 mm below the road surface are about 160 kPa (Figure 3). The relative scatter in the peak values of vertical pressure measured directly under the wheel contact area is, however, now somewhat higher. In addition to the variation of actual axle/wheel loads that was already discussed above, the scatter is partly assumed to be due to the variation in tire inflation pressures between different vehicles, the effect of which could not be taken into account by any means in the analysis of measurement results. At least to some extent, this conclusion is supported by the vertical pressures measured 100 mm deeper inside of the structure (Figure 4). In these results the relative scatter is lower, which could logically be explained by the fact that load spreading is making the effect of actual tire inflation pressure less important at a greater depth.

The measured peak values of vertical compression in the unbound base course layer are of the order of 500 microstrain (Figure 5). In terms of stiffness that corresponds to a value of resilient modulus of the order of 225 MPa if we assume the respective average value of vertical pressure on the distance of the measurement instrument to be somewhere in between the peak values shown in Figures 3 and 4, say 120 kPa. Considering the stress conditions prevailing under a 90 mm thick AC layer this order of stiffness can be considered very plausible.

The recorded peak values of tensile strain at the base of AC layer are in turn of the order of 200 microstrain both in the longitudinal direction (Figure 6) and in the transversal direction of road (Figure 7). The respective peak values of compressive strain both in front of wheel contact area (Figure 6) and on the side of it (Figure 7) are slightly above 50 microstrain.

Remarkable in Figure 7 is the sharp transition from peak tension to peak compression at the edge of tire contact area. If wheel path wander disappears together with the introduction of autonomous vehicles, this point is likely to be one of the critical ones with regard to the service life of road pavements.

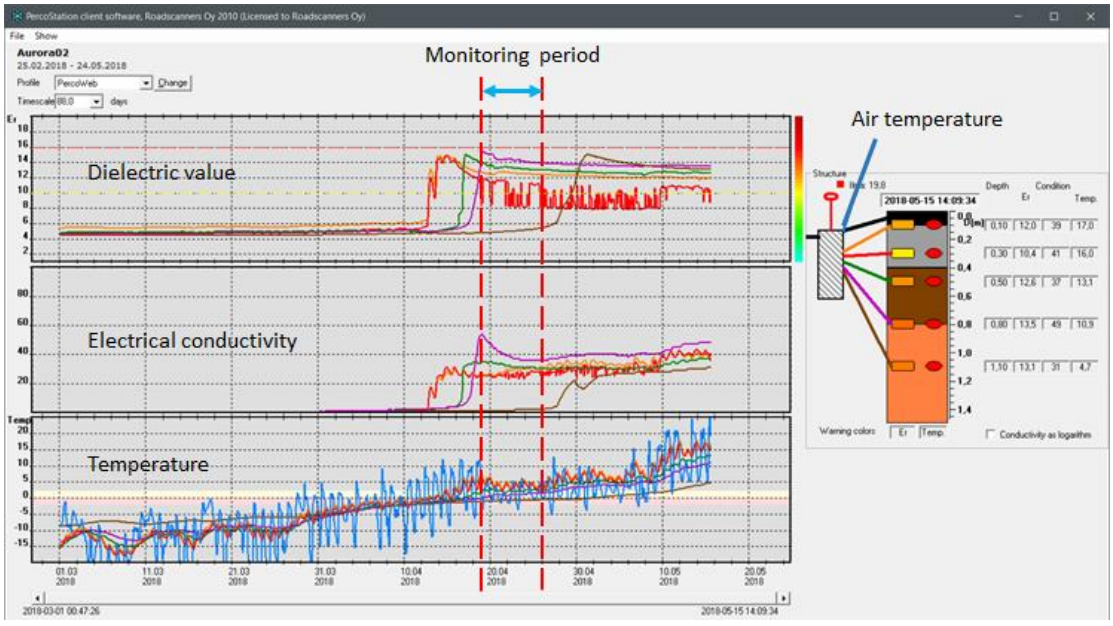

Figure 8. Dielectric values, electrical conductivities and temperatures measure at Aurora 2 test site in the spring 2018.

3.2 Dielectric value, electrical conductivity and temperature

As an example of the results from structural condition monitoring dielectric values, electrical conductivities and temperatures recorded during the spring time of year 2018 at the Aurora 2 monitoring site are shown in Figure 8, in which also the time period corresponding to the structural response measurement results shown in Figures 2 to 7 has been indicated.

From the results of temperature measurements made at different depths below the road surface shown in the lower part of Figure 8, it can be observed that thawing of structural layers has started from the top of road at about the 13th of April and progressed up to the depth of 0.8 m in about a week. At the same time as thawing progresses both the dielectric values and electrical conductivities rise up rapidly alongside with the phase change of water from ice to free water. After reaching a peak value dielectric values start to decrease, which indicates gradual drying of structural layers toward a normal summer time condition.

4 OPEN ACCESS MONITORING DATA

4.1 Structuring of the Aurora monitoring data

A unique feature of the structural monitoring data shortly described in this article is that all the original measurement results are publicly available as open access data via the Finnish Transport Agency website at the address: https://aineistot.liikennevirasto.fi/aurora/

Inside the parent directory Aurora monitoring data is structured in five subfolders (Figure 9). These contain the structural condition data recorded by Percosations, structural response data from Aurora 1 and 2 sites, identified vehicle dimensions and types and the vehicle weights measured at the WIM-station.

Name	
Parent Directory	
percostation/	Condition data
pl4900/	Aurora 2 site
pl5700/	Aurora 1 site
profiling station/	Vehicle types
wim station/	Vehicle weights

Figure 9. Directory structure of the Aurora data.

4.2 Structural response monitoring data

Until the time of writing this manuscript in October 2018, the number of stored heavy vehicle overpasses both at the WIM-station and the Aurora 1 and 2 monitoring sites is several thousands. Due to the very high stiffness of a frozen road structure, the results collected during winter time are hardly meaningful. Therefore, only a limited number of vehicle overpasses is stored before the mid of April 2018 and likewise a limited amount of data is going to be stored during the forthcoming winter periods.

During the unfrozen time, in Muonio region from about the mid of April to the end of October, measurements at Aurora 1 and 2 sites are triggered by vehicles that are inducing a signal that exceeds a set threshold value in one of the selected response measurement transducers. Normally the same vehicle appears first at the WIM-station, about three and a half minutes later at the Aurora 1 site and about 40 seconds after that at Aurora 2 site. Because triggering on each site takes place independently, it may happen that all vehicles do not trigger on both Aurora 1 and 2 sites e.g. if the actual vehicle wheel path on one of the sites is too far from installed instruments.

Duration of each stored data pulse at the Aurora 1 and 2 sites is six seconds per vehicle including at least one second pre-triggering time and a couple of seconds after the vehicle overpass. With the 1 kHz sampling rate this means 6 000 data points per channel per vehicle.

5 CONCLUSIONS

The article presents instrumentations built for comprehensive structural monitoring of two road sections located on the highway E8 in Muonio, Finnish Lapland. In very short, it can be concluded that:

- Nearly all the installed instruments are operative and they seem to produce meaningful results
- All the results collected from thousand of heavy vehicle overpasses can be freely accessed via the FTA website

6 ACKNOWLEDGEMENTS

The authors want to express their sincere thanks to the Finnish Transport Agency for funding the work described above and for providing the opportunity to be a part of the Arctic intelligent transport and infrastruture ecosystem, Aurora.

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