ACCELERATED IMPLEMENTATION OF INTELLIGENT COMPACTION TECHNOLOGY FOR EMBANKMENT SUBGRADE SOILS, AGGREGATE BASE, AND ASPHALT PAVEMENT MATERIALS

Project Report

Route 4, Kandiyohi County, Minnesota
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INTRODUCTION

This project involved mapping the granular subbase layer on Route 4 between Sta. 38+00 to Sta. 168+00 in Kandiyohi County, Minnesota, selecting locations for in-situ testing (LWD, DCP, and FWD) by Mn/DOT personnel, and mapping the HMA non-wearing course layer (nominal 2.5 inch thick) between Sta. 28+58 to Sta. 170+00 (see Figures 1and 2). Sakai SW880 double drum roller (Figure 3) equipped with the CCV measurement system (described below) and differential GPS was used for this project. The subbase layer was mapped on June 15, and the HMA non-wearing course layer was compacted and mapped on June 16 and 17, 2008.

One of the objectives of this project was to investigate the influence of underlying layer support conditions on the HMA layers using intelligent compaction (IC) measurements. This report summarizes project notes and some preliminary analysis results of IC measurements on the subbase and HMA non-wearing course layer.

In brief, results obtained at this site show that the IC measurement values on the subbase layer are reflected to the HMA layer IC measurement values and that mapping the subbase layer can be a useful way to identify poor support conditions. About 60 m (200 ft) of HMA non-wearing course layer reportedly "failed" after compaction, under construction traffic. Low CCV measurements were observed on the HMA and the underlying subbase layer in this zone. Interestingly, this zone was located within an area of the project where the subgrade layer was reportedly "failed" under test rolling in Summer 2007. A review of the Kandiyohi Soil Survey data showed that this "failed" zone is located in an area of peat/muck soil deposits.

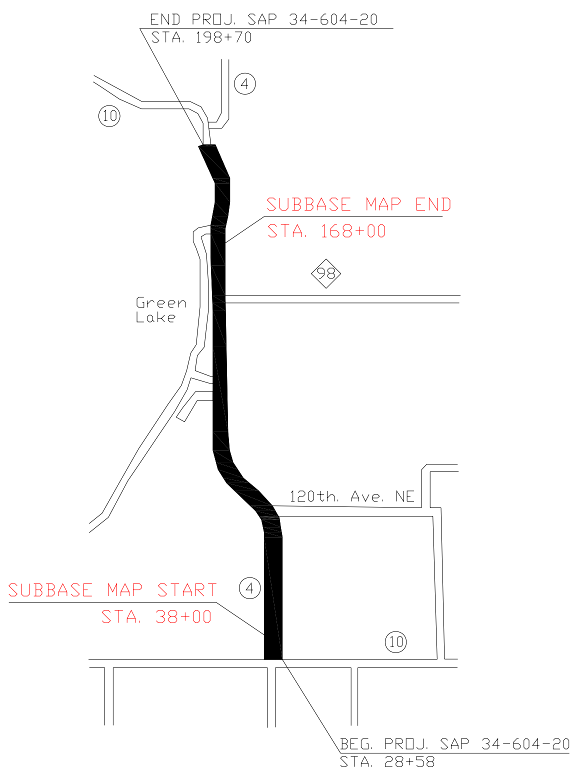


Figure 1. Plan view of the Route # 4 project site

Figure 2. Photos of subbase layer along Route 4

Figure 3. Sakai SW880 double drum roller

SITE CONDITIONS AND SOIL SURVEY INFORMATION

Based on the project drawings provided by Kandiyohi County Public Works Department, the project area consists of approximately 1 to 3 m (3 to 10 ft) thick compacted subgrade material placed over the previous grade of Route 4. Reportedly, the subgrade layer between Sta. 134+00 and 144+00 (located south of CR 98) "failed" under test rolling during Summer 2007 (personal communication with Jeo Steffen, County Public Works Department). Later, the subgrade layer was capped with 150 mm (6 in) of class 5 aggregate subbase material (Minnesota aggregate subbase classification). After installing the subbase layer, the aggregate surface road has been open for traffic.

Kandiyohi County Soil Survey information (NRCS 2008) indicates that the majority of natural soils in the project area are derived from glacial till and glacial outwash materials. These include Estherville-Hawick complex, Koronis-Sunburg complex, Sunburg-Wadenill complex, Canisteo-harps loams, Webster silty clay loam, and Grovecity loam soil series. These soils are classified as CL, CL-ML, ML, SC, SC-SM, and SM according to the USCS classification system. Portions of the project area consist of muck herbaceous organic materials of Houghton muck (near the north end of the project) and Palms muck (south of CR 98) soil series. These soils are classified as PT according to USCS classification system, and are very poorly drained with the water table at surface. These peat/muck soils are highly compressible and typically have natural moisture contents in the range of 40% to 100%. Additional information about these soil series is provided in Appendix A (NRCS 2008).

The approximate location of the area that "failed" under test rolling (Sta. 134+00 to 144+00) is highlighted on the soil survey map presented in Figure 4. The natural soils in this area consist of Palms muck soil series with sandy substratum (shown as soil series 548). According to NRCS (2008), these soils contain muck to a depth of about 0.7 m (27 in) underlain by clay loam and sandy soils to a depth of about of 1.5 m (60 in), below natural grade. A review of project drawings indicates that approximately 1 m to 2 m (3 ft to 6 ft) of new subgrade fill was placed over the previous grade in this region. No information on treatment of the muck soils present in this region during construction or type of new subgrade fill material used for construction of the new grade is available at this time of the report. Full depth DCP tests up to 2 m would be useful in this area to give a quick indication of the soil profile.

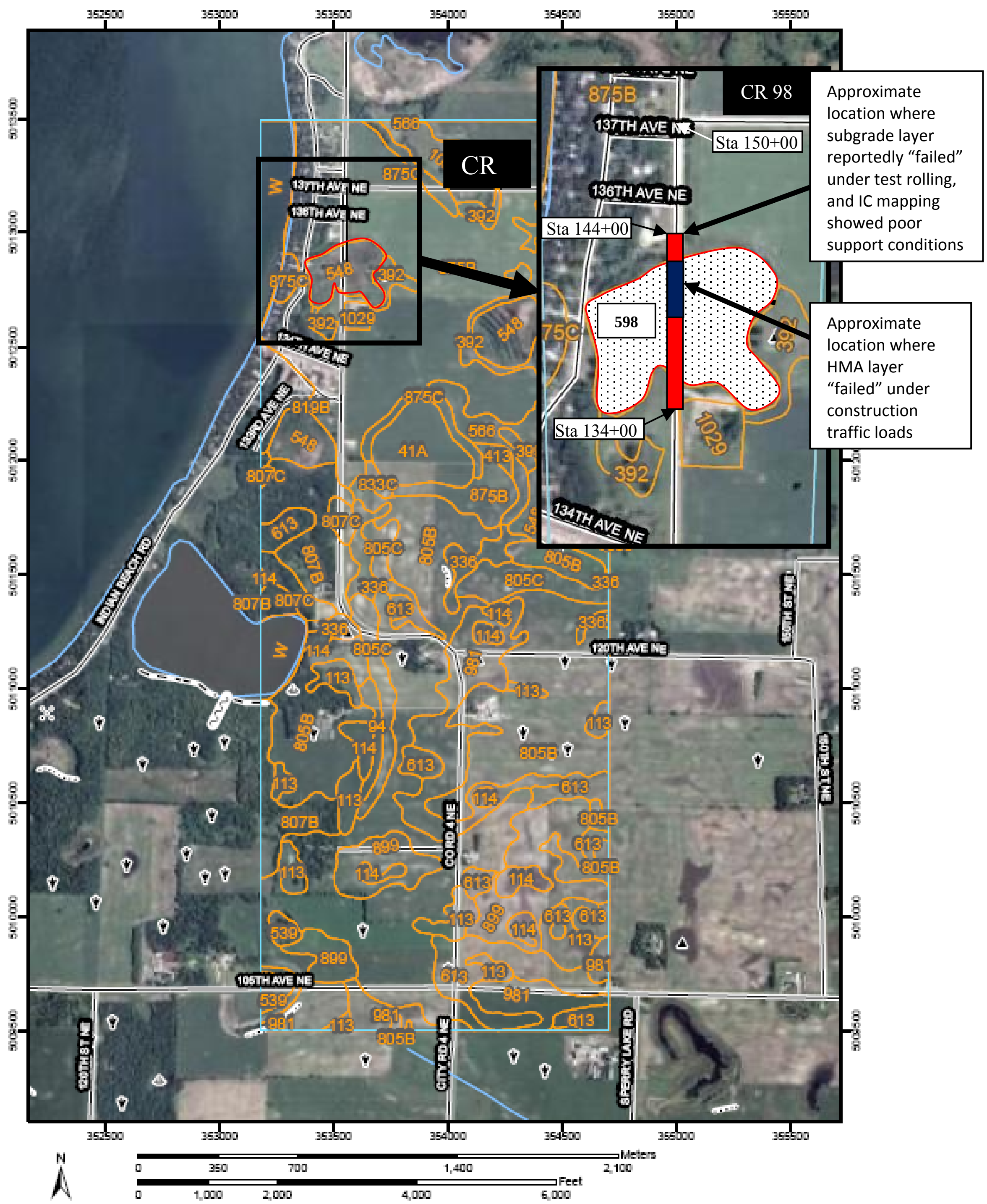


Figure 4. Aerial image with soil survey information of the project area (NRCS 2008)

SAKAI CCV MEASUREMENT SYSTEM

Sakai *Compaction Control Value* (CCV) is a vibratory-based technology which makes use of an accelerometer mounted to the roller drum to create a record of machine-ground interaction with the aid of GPS. The concept behind the CCV is that as the ground stiffness increases, the roller drum starts to enter into a "jumping" motion which results in vibration accelerations at various frequency components. This is illustrated in Figure 4. The CCV is calculated by using the acceleration data from first subharmonic (0.5Ω), fundamental (Ω), and higher-order harmonics (1.5Ω, 2Ω, 2.5Ω, 3Ω) as presented in Eq. 1. The vibration acceleration signal from the accelerometer is transformed through the Fast Fourier Transform (FFT) method and then filtered through band pass filters to detect the acceleration amplitude spectrum (Nohse and Kitano 2002, Scherocman et al. 2007). The Sakai SW880 roller used on the project is shown in Figure 1, and its features are summarized in Table 1. CCV measurements on the SW880 model are made using the accelerometer mounted on the front drum of the roller.

$$CCV = \left[\frac{A_{0.5\Omega} + A_{1.5\Omega} + A_{2\Omega} + A_{2.5\Omega} + A_{3\Omega}}{A_{0.5\Omega} + A_{\Omega}} \right] \times 100 \tag{1}$$

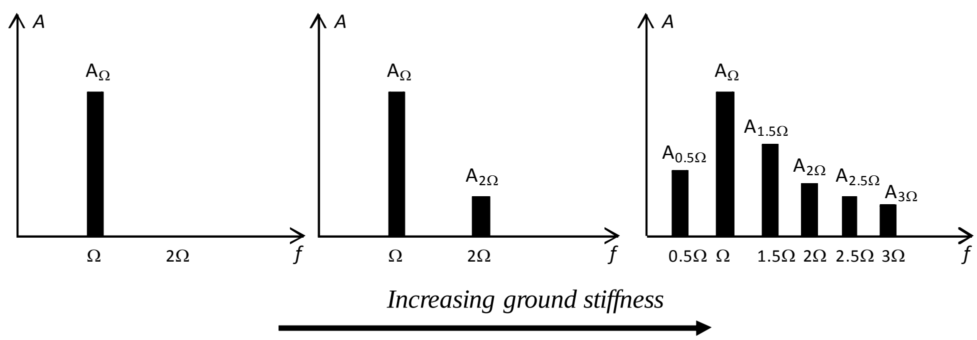


Figure 5. Changes in amplitude spectrum with increasing ground stiffness (modified from Sakai Manual)

Table 1. Features of the roller used on the project

Feature	Description
Model	Sakai SW880 Double Drum Roller (Figure 3)
Frequency	2500, 3000, 4000 vpm
Amplitude	0.3 mm (low), 0.6 mm (high)
Measurement	Sakai CCV (Continuous Compaction Value)
Display Software	Aithon MT-R ver 1.0 (Figures 6 and 7)
GPS coordinates	UTM NAD83 MN central state plane coordinates
Documentation	Location (Northing/Easting and Latitude/Longitude), Elevation, CCV, Temperature, Frequency, Direction, GPS Quality

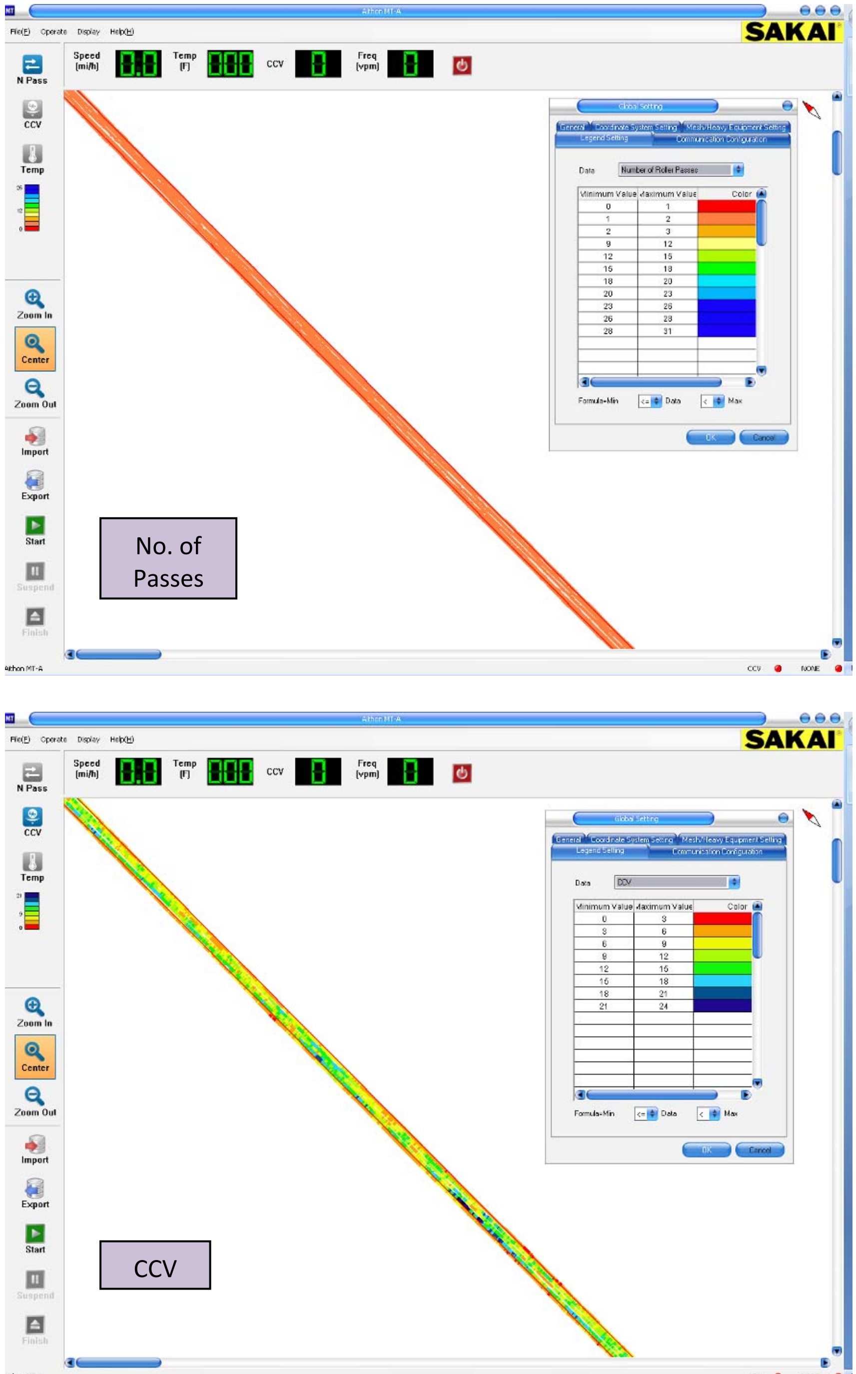


Figure 6. Aithon MT-A software output for number of passes and CCV

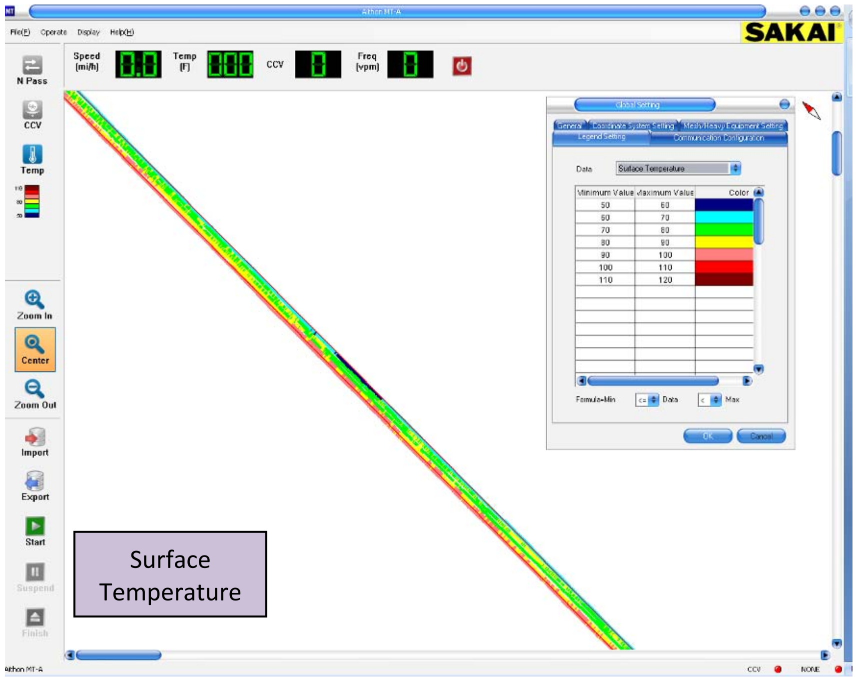


Figure 7. Aithon MT-A software output for surface temperature

SUBBASE LAYER AND HMA NON-WEARING COURSE LAYER MAPPING

Mapping Operations

The granular subbase layer was mapped in five roller lanes which included three roller lanes to cover the north bound (NB) and south bound (SB) pavement lanes, and two roller lanes to cover the NB and SB shoulders (Figure 8) using two machine operation settings as described below. The front drum was in vibration mode while the rear drum was in static mode during the mapping process. The machine was operated at a constant nominal speed of about 4.8 km/h (3 mph), however, it was noticed on the digital speed display that the speed fluctuated between 4.8 to 5.4 km/h (3 to 3.4 mph). Actual speed output is not available as part of the roller output data.

- Subbase map 1: f = 2500 vpm, a = 0.6 mm (high amp), v = 4.8 km/h (3.0 mph)
- Subbase map 2: f = 3000 vpm, a = 0.3 mm (low amp), v = 4.8 km/h (3.0 mph)

The vibration frequency setting of 4000 vpm on the subbase layer showed unreasonably high CCV-values (~ 60 to 120). Sakai personnel measured the frequency of the drum vibration on-site and it was confirmed that the machine was vibrating at about 4000 to 4100 vpm, however, the roller output was showing frequency values in the range of 3400 and 3600 vpm. It was presumed that the discrepancy in frequency measurement by the sensors in the roller drum could be the cause of the high CCV values. Due to uncertainty in the measured CCV values at f = 4000 vpm, roller data was not obtained in this setting.

The HMA non-wearing course layer was compacted at a = 0.3 mm and f = 4000 vpm on the SB lane between Sta. 28+58 and Sta. 34+60. The rest of the project area was compacted at a = 0.6 mm and f = 3000 vpm (Figure 9). The data obtained at f = 4000 vpm setting was filtered in the results presented later in this report due to uncertainty in the validity of the CCV measurements at this setting. Compaction was performed using two vibratory roller passes with both front and rear drums in vibration mode. CCV data obtained from the second roller pass is analyzed and presented later in this report. Digital speed display on the roller was not functional at the time of rolling operations on the HMA non-wearing course layer. Therefore, the operation speed information for this layer is not available.

Figure 8. Subbase layer mapping operation (photo courtesy of Sakai)

Figure 9. HMA non-wearing course layer compaction/mapping operation

Results and Discussion

Histogram plots of subbase map 1, subbase map 2, and HMA non-wearing course layer map (second pass) are presented in Figures 10, 11, and 12, respectively. Color-coded CCV maps for the subbase layer (subbase map 1 and map 2), and the HMA non-wearing course layer are provided in Appendix B.

At 0.6 mm amplitude setting (subbase map 1), CCV-values on the shoulder lanes were lower compared to CCV-values on the pavement lanes. Average CCV on the pavement lanes was about 1.5 times greater than average CCV on shoulder lanes (Figure 10). The average measured drum vibration frequency (~ 2540 vpm) was close to the target frequency setting of 2500 vpm. Field observations indicate that the shoulders were not subjected to as much traffic as vehicles were predominantly driven within the pavement lanes.

At 0.3 mm amplitude setting (subbase map 2), CCV-values on the shoulder lanes and pavement lanes have similar frequency distributions and average values (Figure 11). The measured drum vibration frequency was about 3180 vpm which was greater than the 3000 vpm target setting. CCV-values at the 0.3 mm amplitude setting were on average about 1.5 times greater (based on values along the pavement lanes – three roller lanes) than CCV-values at the 0.6 mm amplitude setting. Also, CCV-values showed less non-uniformity with C_v (coefficient of variation) of about 27% (a = 0.3 mm) compared to C_v of about 52% (a = 0.6 mm).

For the HMA non-wearing course layer, average CCV on the pavement lanes was about 6.9 with C_v of about 33% (Figure 12). The measured drum vibration frequency (~ 3000 vpm) was close to the target frequency setting of 3000 vpm for the HMA wearing course layer.

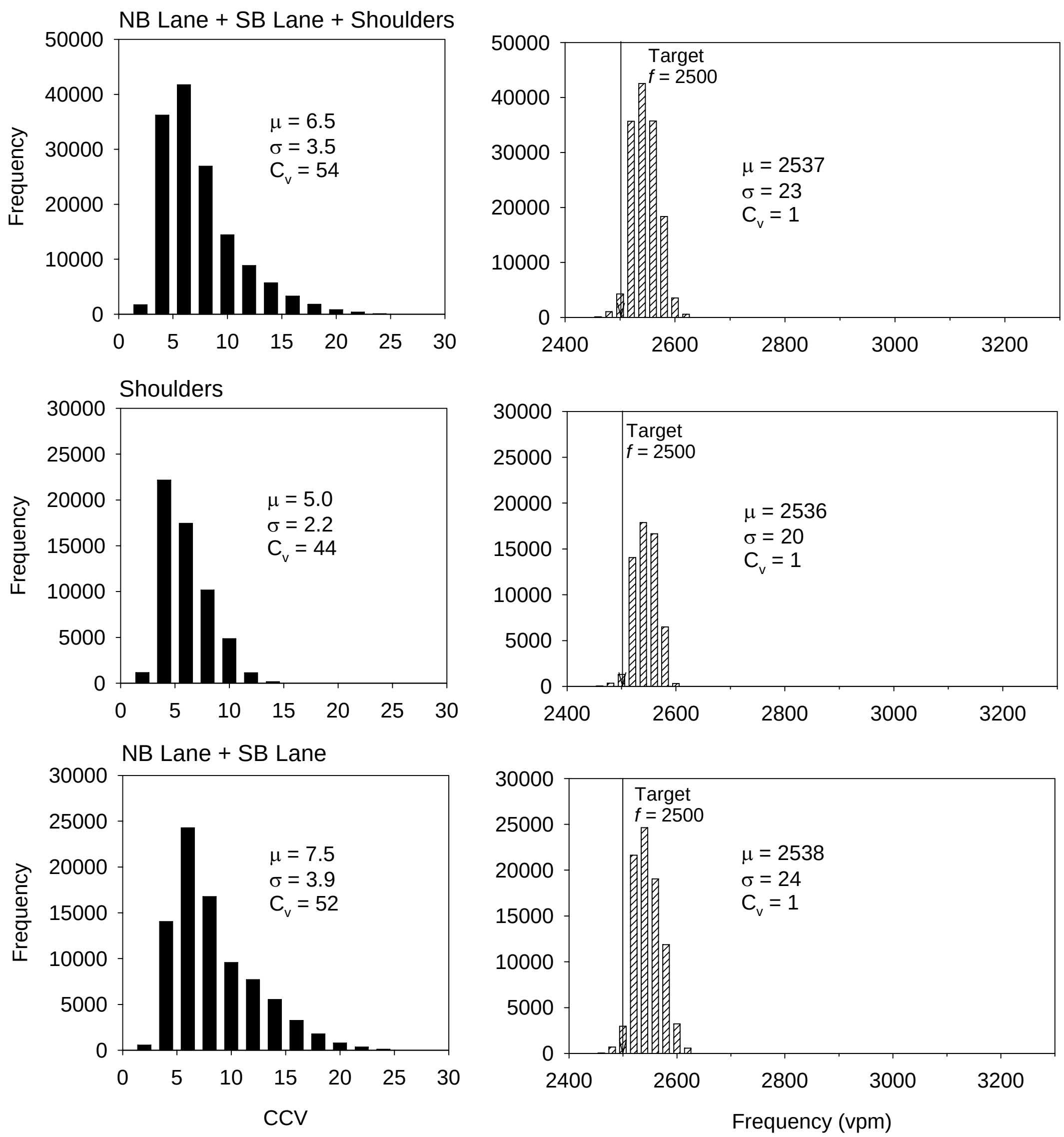


Figure 10. CCV and frequency histograms for subbase map 1 (*a* = 0.6 mm)

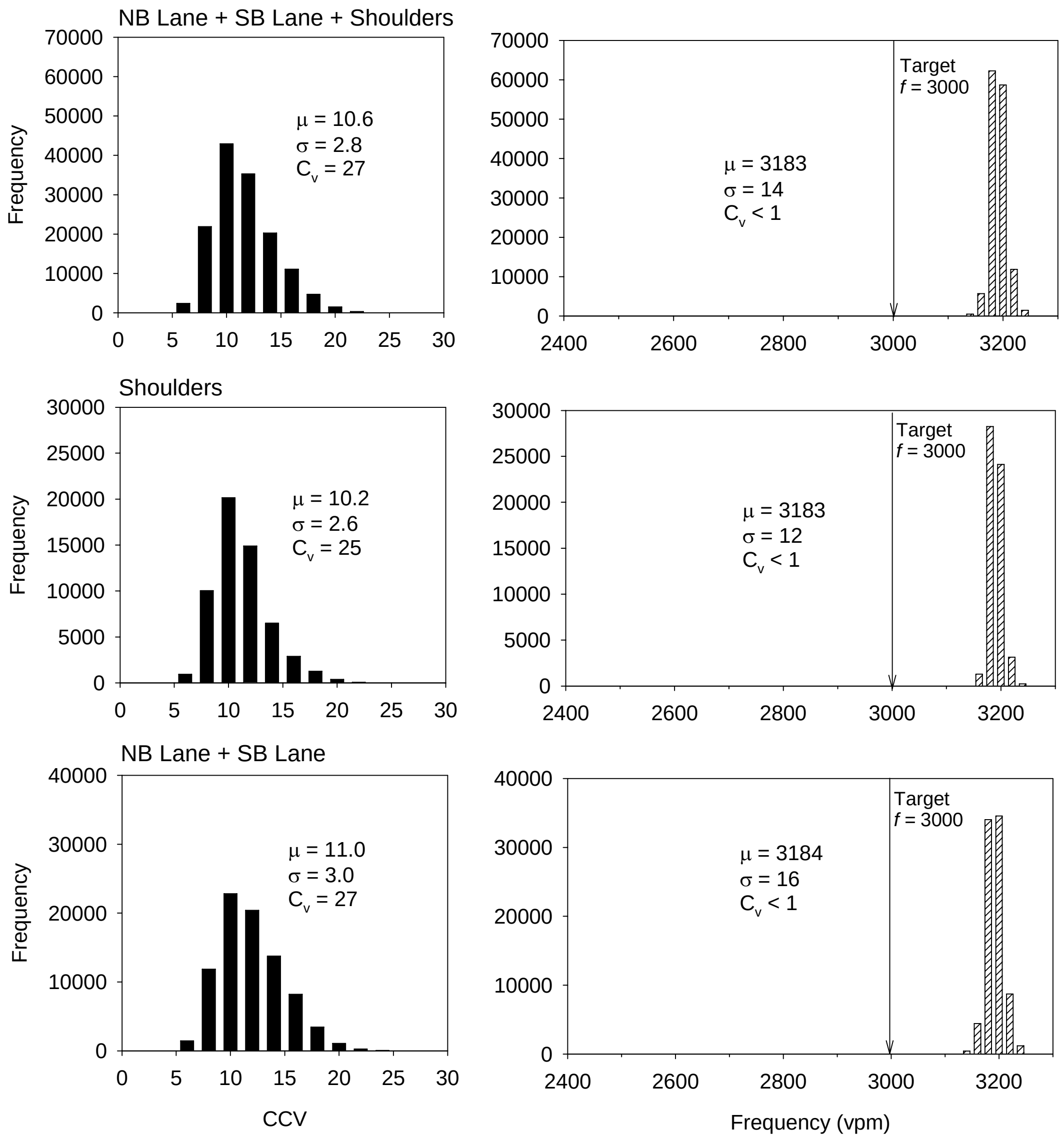


Figure 11. CCV and frequency histograms for subbase map 2 (*a* = 0.3 mm)

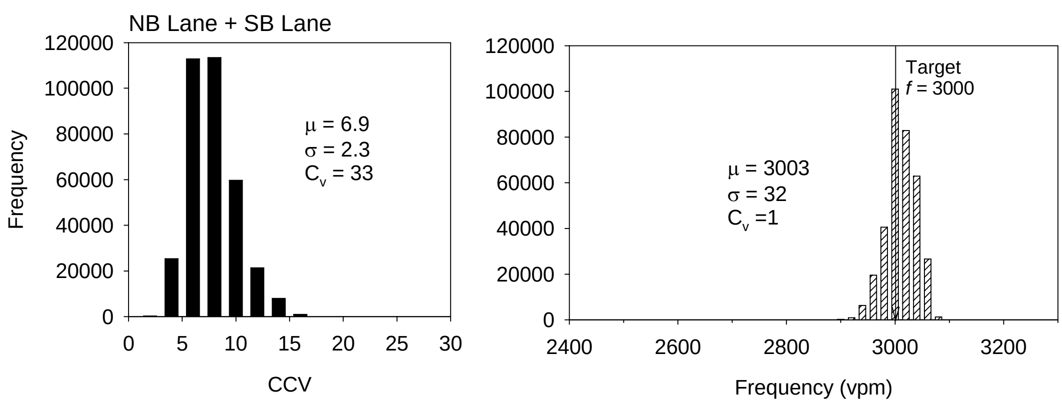


Figure 12. CCV and frequency histograms for HMA non-wearing course map (*a* = 0.6 mm)

Figure 13 shows CCV maps of the HMA non-wearing course layer and the underlying subbase layer for a 210 m (700 feet) long section with heterogeneous subbase. Figure 14 compares CCV measurements (raw data and 5 m moving average) on HMA non-wearing course and subbase layers over a 1300 m (4000 feet) long section along the SB pavement lane. CCV measurements on subbase layer obtained at a = 0.3 mm and a = 0.6 mm setting are presented in Figure 14 for comparison. Figures 13 and 14 show locations of high CCV and low CCV areas on the subbase layer (measured at a = 0.6 mm) reflecting on CCV measurements on the HMA layer. Measurements obtained at a = 0.3 mm setting did not clearly differentiate soft/hard zones on the subbase layer. Data presented in Figure 14 is further analyzed using regression analysis as presented in Figure 15. Regression relationships in Figure 15 indicate statistically strong relationship between CCV measurements obtained on the HMA non-wearing course layer and subbase layer at a = 0.6 mm setting with R^2-value of about 0.7. CCV measurements obtained on the subbase layer at a = 0.3 mm show relatively poor correlation to CCV measurements on the HMA layer.

Following compaction operations on the HMA non-wearing course layer on the SB lane, premature "failure" cracks were observed over a 200 feet long section (Sta 140+12 to 142+61) on the HMA layer under construction traffic (Figure 14). To further evaluate the condition, the CCV measurements on the HMA wearing course layer and the subbase layer in this area were compared as shown in Figures 17 and 18. The data shows average CCV = 2.5 for the subbase layer which is considerably lower than the project average CCV = 7.5. Average CCV on the HMA wearing course in the area was about 5.2, which is also lower than the project average of about 6.9. This area is located within the area where the subgrade layer reportedly "failed" under test rolling in Summer 2007 (Sta. 134+00 to 144+00). Again, the underlying natural soils in this section were identified in the soil survey as consisting of peat/muck soil deposits (see Figure 4).

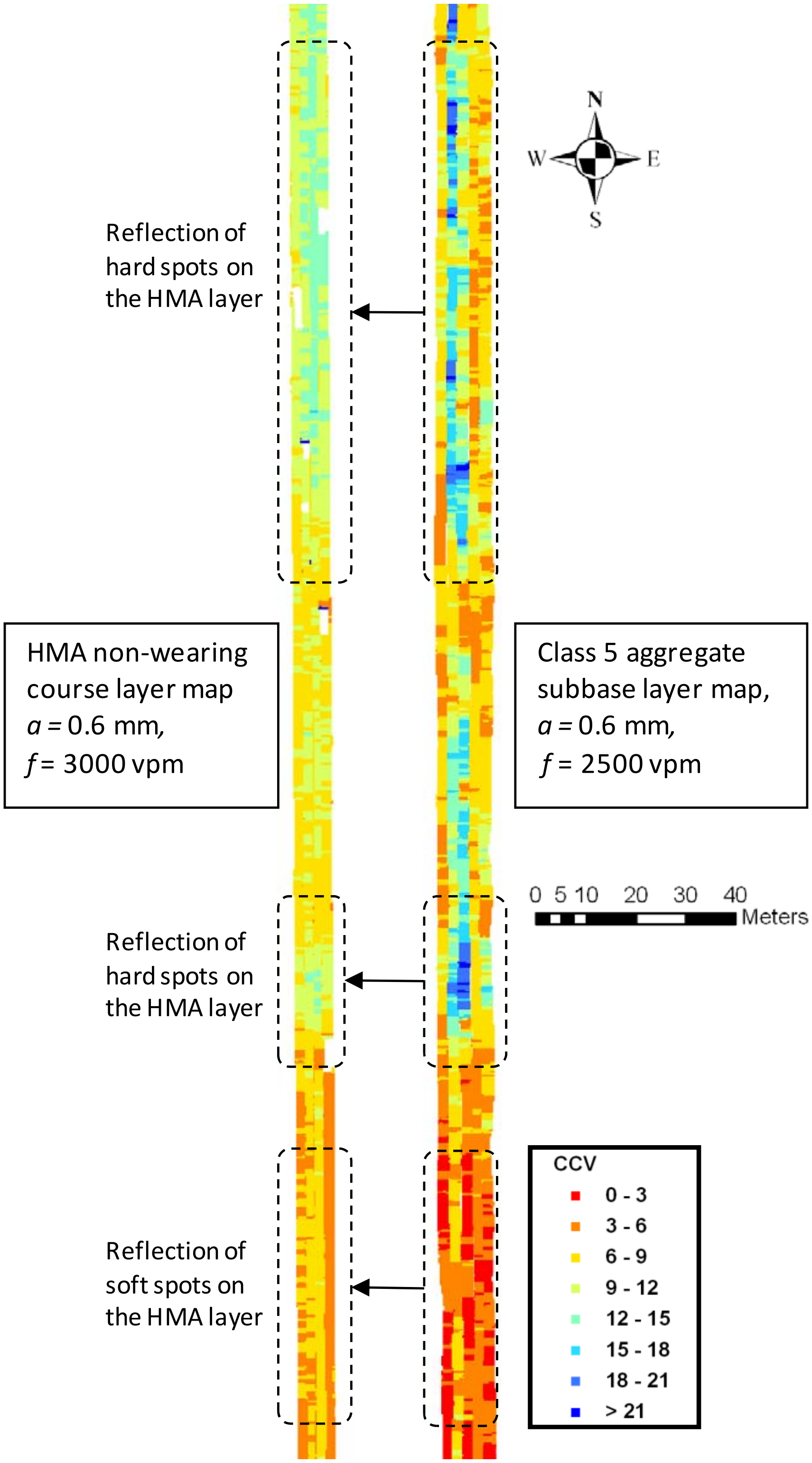


Figure 13. Comparison of HMA non-wearing course layer and subbase layer map showing the influence of underlying layer heterogeneity

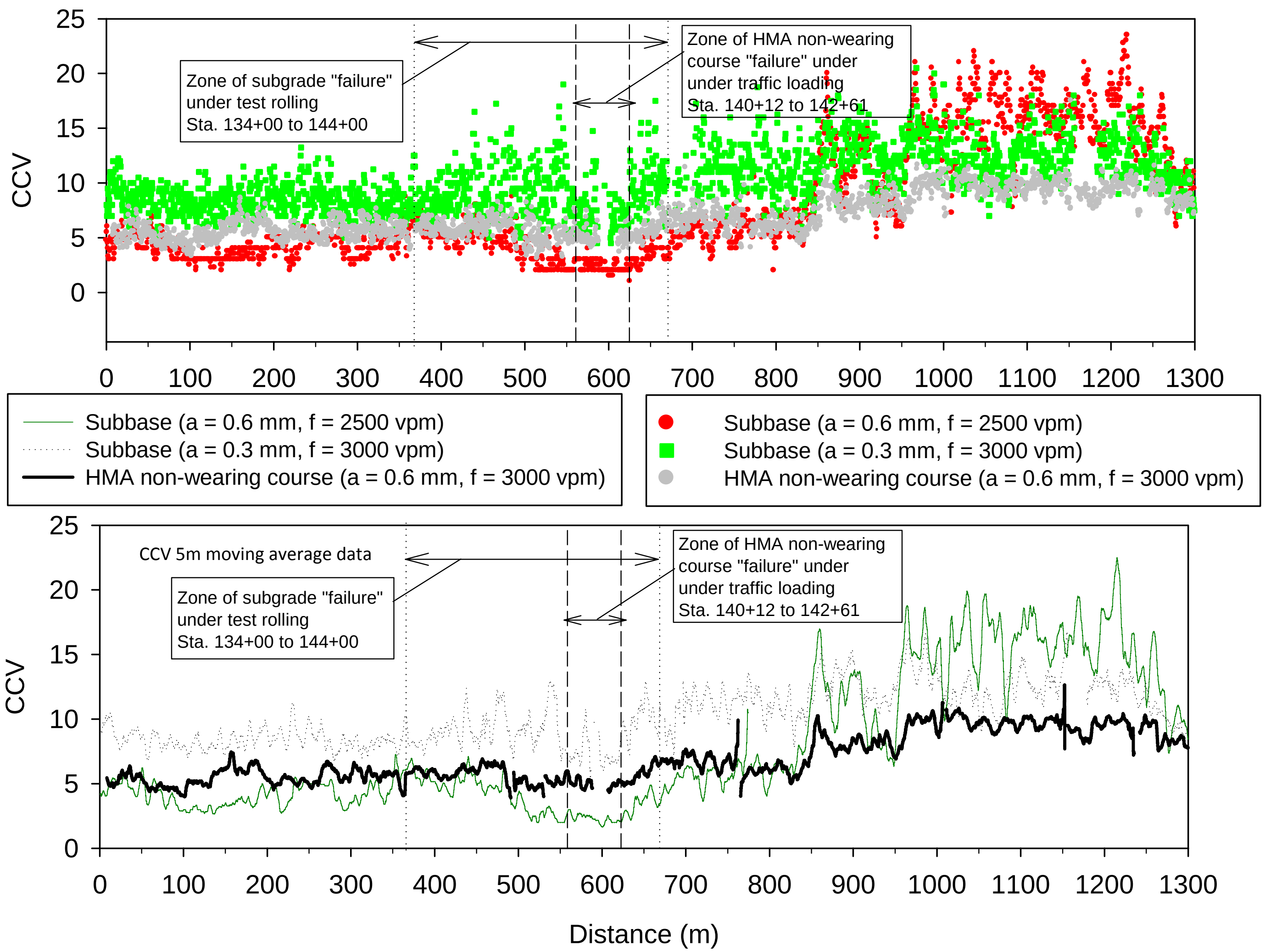


Figure 14. Comparison of CCV measurements on HMA non-wearing course layer and subbase layer

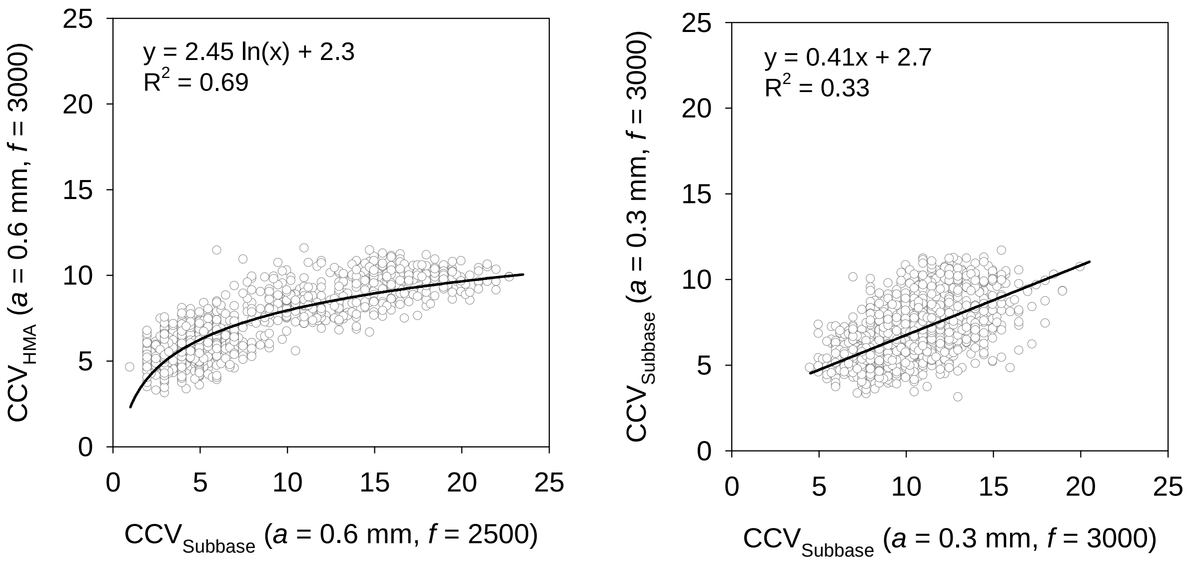


Figure 15. Simple regression relationships between CCV measurements on subbase and HMA non-wearing course layer

Figure 16. Premature failure observed in the HMA non-wearing course layer between Sta. 140+12 and Sta. 142+61

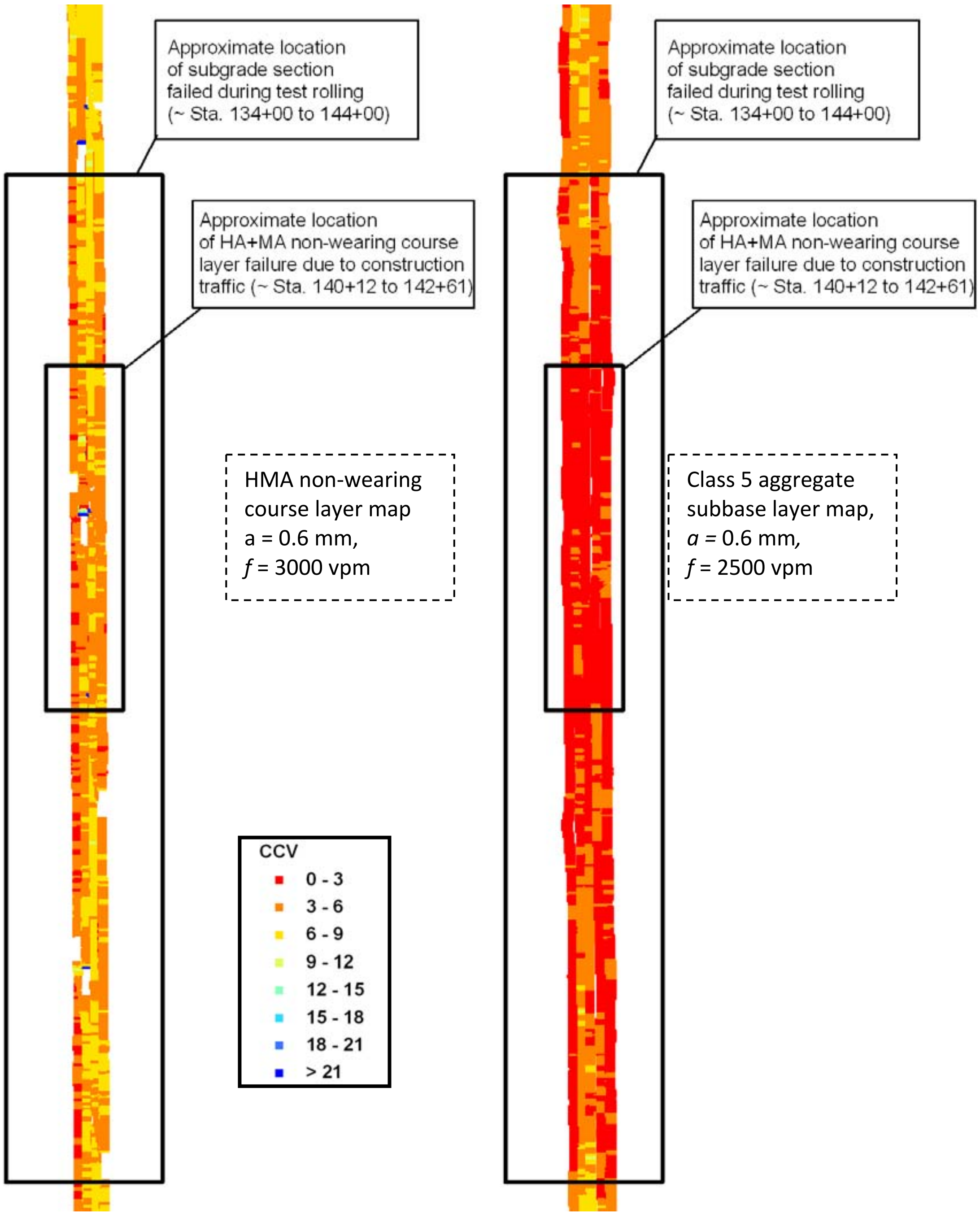


Figure 17. Comparison of HMA non-wearing course layer and subbase layer maps

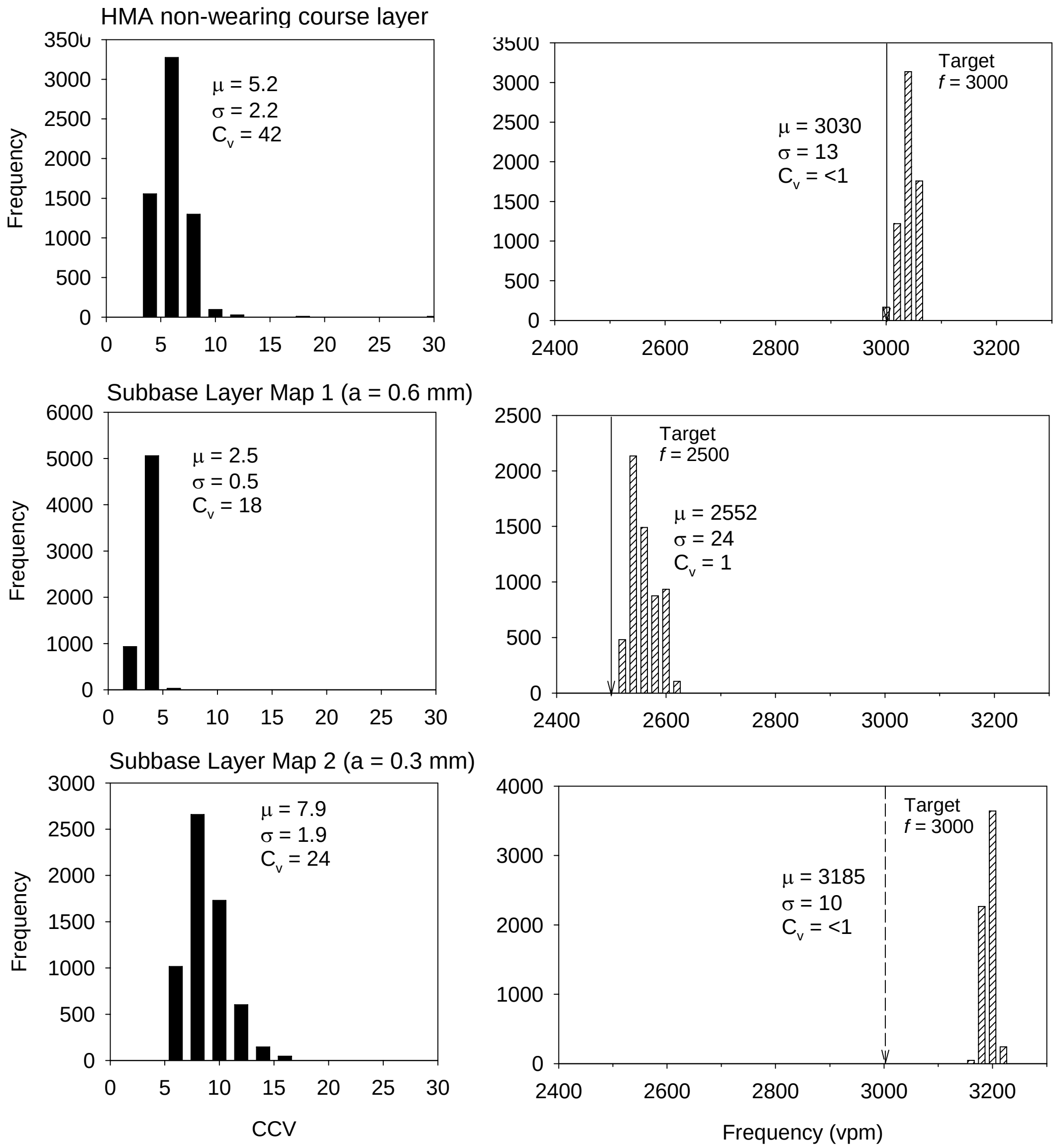


Figure 18. CCV and operation frequency comparison between HMA non-wearing course layer, subbase layer map 1, and subbase layer map 2 between Sta. 140+12 to 142+61.

SUMMARY AND KEY FINDINGS

This report summarizes our field investigation with preliminary analysis of the IC measurements collected using the Sakai SW880 roller for the subbase and HMA non-wearing course layers on Route 4 in Kandiyohi County, Minnesota. The subbase layer was mapped using high (a = 0.6 mm) and low (a = 0.3 mm) amplitude settings, and most of the HMA non-wearing course layer was mapped using the high amplitude (a = 0.6 mm) setting. Some key findings from this project are as follows:

- CCV measurements on the subbase layer at 0.3 mm amplitude setting were on average about 1.5 times greater than CCV measurements at high amplitude setting.

- For the 0.3 mm amplitude setting, CCV-values showed lower non-uniformity with C_v (coefficient of variation) = 27% compared to C_v = 52% for the 0.6 mm amplitude setting.
- For the 0.6 amplitude setting, average CCV on the shoulder lanes were about 1.5 times lower than on the pavement lanes. For the 0.3 amplitude setting, average CCV on shoulder and pavement lanes was about the same.
- For the HMA non-wearing course layer, average CCV on the pavement lanes = 6.9 with C_v = 33%.
- Comparison between CCV maps on the HMA non-wearing course layer and subbase layer (a = 0.6 mm) showed several locations of high and low CCV that reflect to the HMA layer. Regression relationships between CCV measurements on the subbase layer at 0.6 mm amplitude setting and on the HMA layer showed strong correlations with R^2 = 0.7. This demonstrates the importance of the knowledge of the underlying layer in interpreting CCV measurements at the surface, which has not been well documented in the literature.
- CCV measurements obtained on the subbase layer at 0.6 mm amplitude setting better distinguished the hard/soft spots compared to CCV measurements obtained at 0.3 mm amplitude setting.
- Following compaction and mapping of the HMA non-wearing course layer on the SB lane, premature "failure" cracks were observed over a 200 feet long section on the HMA layer. Average CCV of the underlying subbase layer in this area = 2.5 which is considerably lower than the project average CCV = 7.5. Average CCV on the HMA non-wearing course in the area = 5.2 which is also lower than the project average = 6.9. This area is located within the area where the subgrade layer reportedly "failed" under test rolling in Summer 2007, and is an area identified on NRCS soil survey maps consisting of peat/muck soils.

PRELIMINARY RECOMMENDATIONS

Some preliminary recommendations based on the analysis and findings in this report are as follows:

- IC measurements obtained from this project demonstrated the importance of the underlying layer support on the performance of the HMA surface layer. Where possible, it is important to obtain IC measurements of the underlying layers to better interpret the measurements on the HMA surface layers.
- CCV measurements obtained at 0.6 mm amplitude setting may better identify hard/soft spots compared to CCV measurements obtained at 0.3 mm amplitude setting. Influence of amplitude on CCV measurements should be evaluated further in future projects.
- In-situ test measurements (LWD, DCP, and FWD) obtained by Mn/DOT should be analyzed in conjunction with the IC measurements to better interpret the results.
- CCV measurements obtained on the HMA wearing course layer installed over the HMA non-wearing course layer should be analyzed in a similar fashion if possible.

- Multiple regression analysis of the CCV measurements on the HMA layers and subbase layers should be conducted with incorporating HMA temperature data into the regression model.
- Performance monitoring inspections, i.e., crack survey inspections on the HMA layer, should be carried out a few times a year to identify performance trends that relate to CCV values.
- 2-m (6 ft) deep DCP tests should be performed immediately in the location of low CCV areas to further investigate the stiffness of the subgrade layers below the granular subbase.

REFERENCES

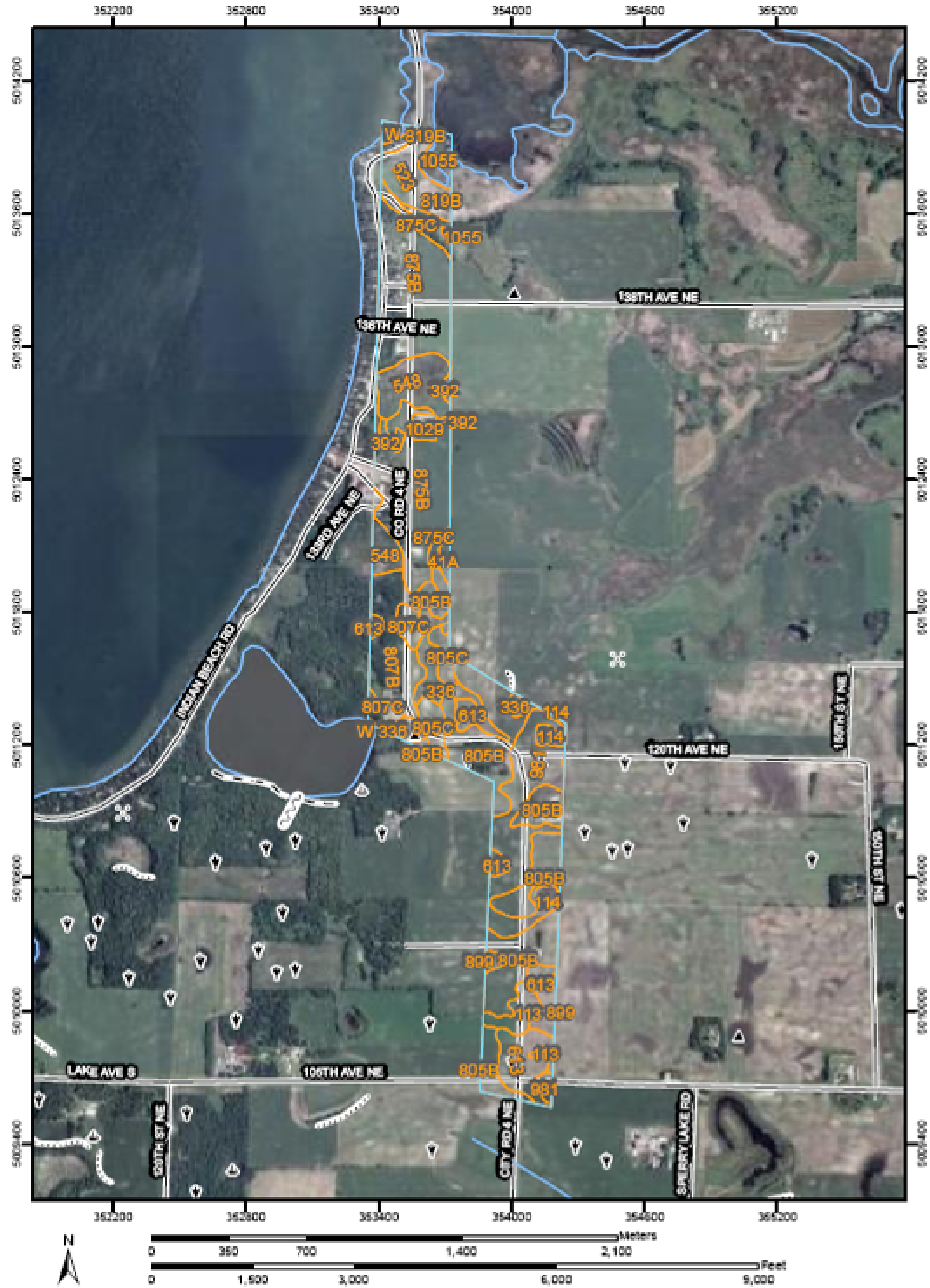
Nohse, Y., and Kitano, M. (2002). "Development of a new type of single drum vibratory roller," *Proc. 14th Intl. Conf. of the Intl. Soc. For Terrain-Vehicle Systems,* Vicksburg, MS, October 20-24.

Sakai Heavy Industries, Ltd. Vibrating Roller Type Soil Compaction Quality Controller CCV (Compaction Control Value), Operating & Maintenance Instructions.

Scherocman, J., Rakowski, S., and Uchiyama, K. (2007). "Intelligent compaction, does it exist?" 2007 *Canadian Technical Asphalt Association (CTAA) Conference,* Victoria, BC, July.

NRCS (2008). *Web Soil Survey*, Natural Resources Conservation Service (NRCS), United States Department of Agriculture (USDA). <http://websoilsurvey.nrcs.usda.gov/ > accessed June 20, 2008.

APPENDIX A: AERIAL IMAGES AND SOIL SURVEY INFORMATION (NRCS 2008)


138TH AVE NE
136TH AVE NE
CO RD 4 NE
133RD AVE NE
INDIAN BEACH RD
120TH AVE NE
150TH ST NE
160TH ST NE
LAKE AVE S
108TH AVE NE
CITY RD 4 NE
SPERRY LAKE RD
W 819B
1055
523
819B
875C
875B
548
392
1029
41A
805B
613
807C
807B
805C
336
W 336
114
981
899
113
Meters
0 350 700 1,400 2,100
Feet
0 1,500 3,000 6,000 9,000
N

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Units

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Gully

Short Steep Slope

Other

Political Features

Municipalities

Cities

Urban Areas

Water Features

Oceans

Streams and Canals

Transportation

Rails

Roads

Interstate Highways

US Routes

State Highways

Local Roads

Other Roads

MAP INFORMATION

Original soil survey map sheets were prepared at publication scale. Viewing scale and printing scale, however, may vary from the original. Please rely on the bar scale on each map sheet for proper map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 15N

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Kandiyohi County, Minnesota
Survey Area Data: Version 7, May 15, 2008

Date(s) aerial images were photographed: 1991

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

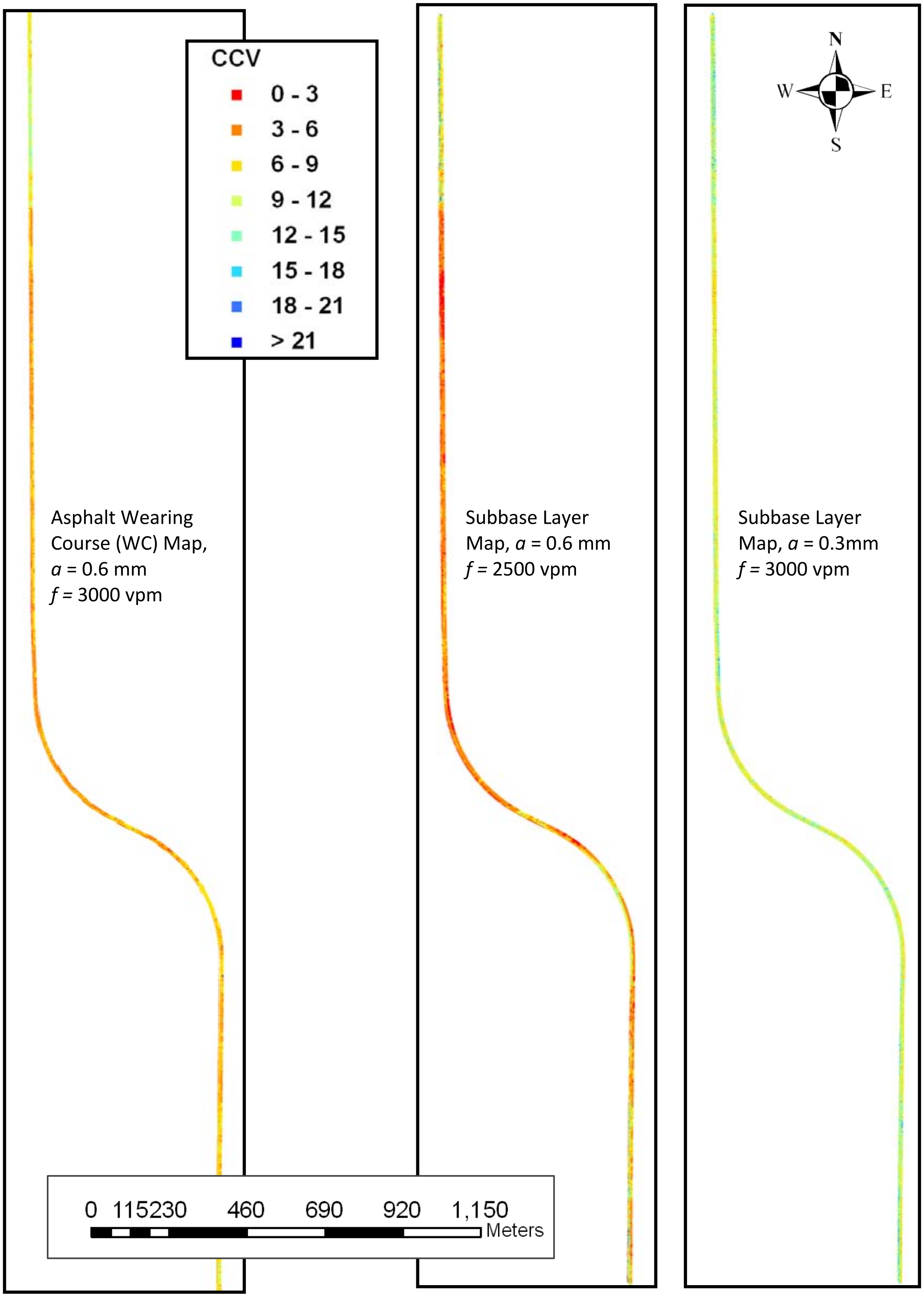
Kandiyohi County, Minnesota (MN067)			
Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
41A	Estherville coarse sandy loam, 0 to 3 percent slopes	2.1	0.5%
113	Webster silty clay loam	8.9	2.2%
114	Glencoe clay loam	4.7	1.2%
336	Delft loam	18.4	4.6%
392	Biscay loam	3.5	0.9%
523	Houghton muck	17.1	4.3%
548	Palms muck, sandy substratum	24.1	6.0%
613	Grovecity loam	22.5	5.6%
805B	Wadenill-Sunburg loams, 2 to 6 percent slopes	83.7	20.9%
805C	Sunburg-Wadenill complex, 6 to 12 percent slopes	10.3	2.6%
807B	Koronis-Sunburg complex, 2 to 6 percent slopes	26.3	6.6%
807C	Koronis-Sunburg complex, 6 to 12 percent slopes	8.0	2.0%
819B	Regal-Hawick complex, 0 to 4 percent slopes	4.7	1.2%
833C	Sunburg-Wadenill-Hawick complex, 6 to 12 percent slopes	1.8	0.5%
875B	Estherville-Hawick complex, 2 to 6 percent slopes	97.1	24.2%
875C	Hawick-Estherville complex, 6 to 12 percent slopes	7.0	1.7%
899	Harps-Okoboji complex	6.1	1.5%
981	Canisteo-Harps loams	41.2	10.3%
1029	Pits, gravel	3.2	0.8%
1055	Aquolls and Histosols, ponded	7.3	1.8%
W	Water	2.4	0.6%

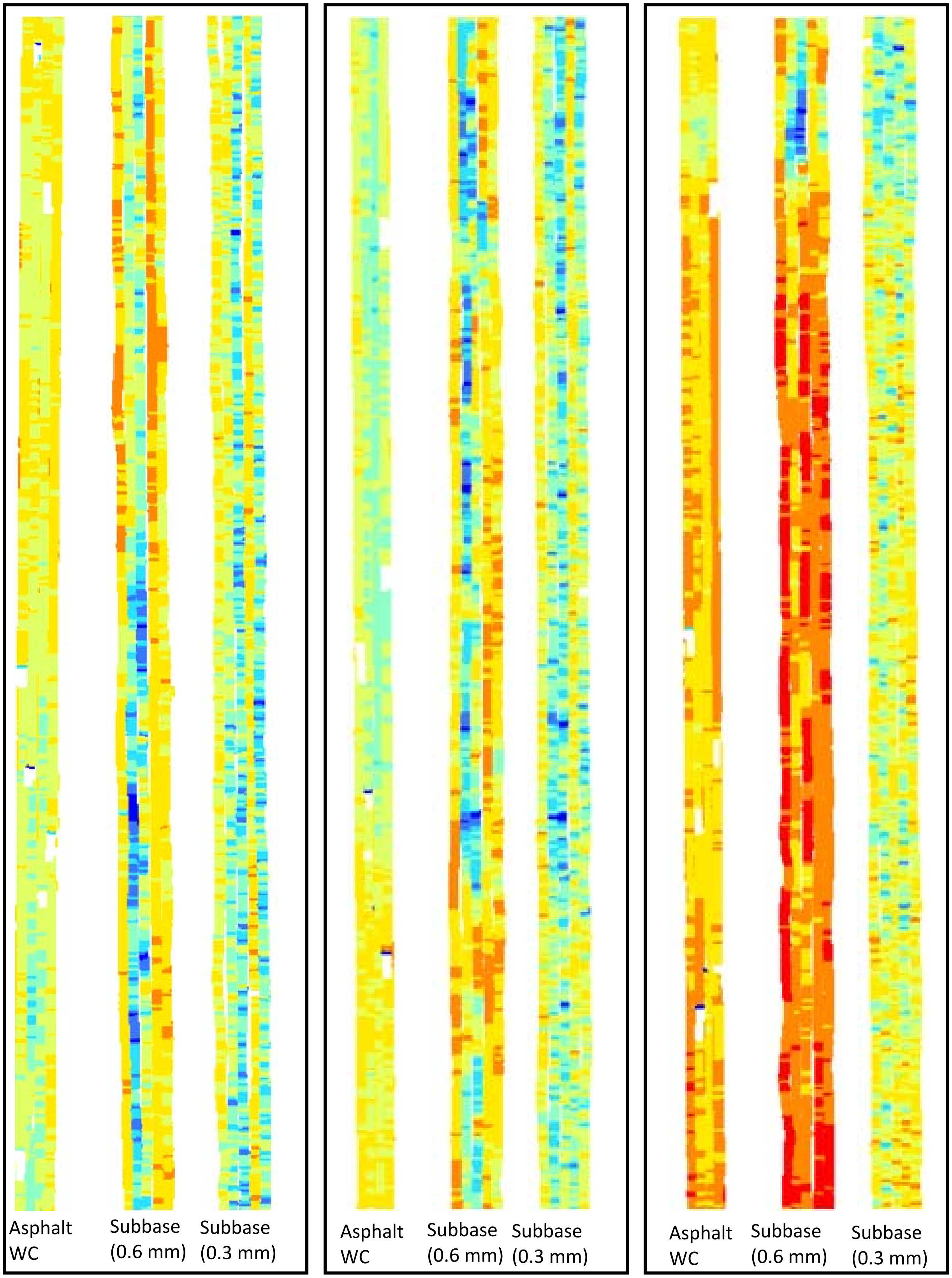
Totals for Area of Interest (AOI)	400.4	100.0%

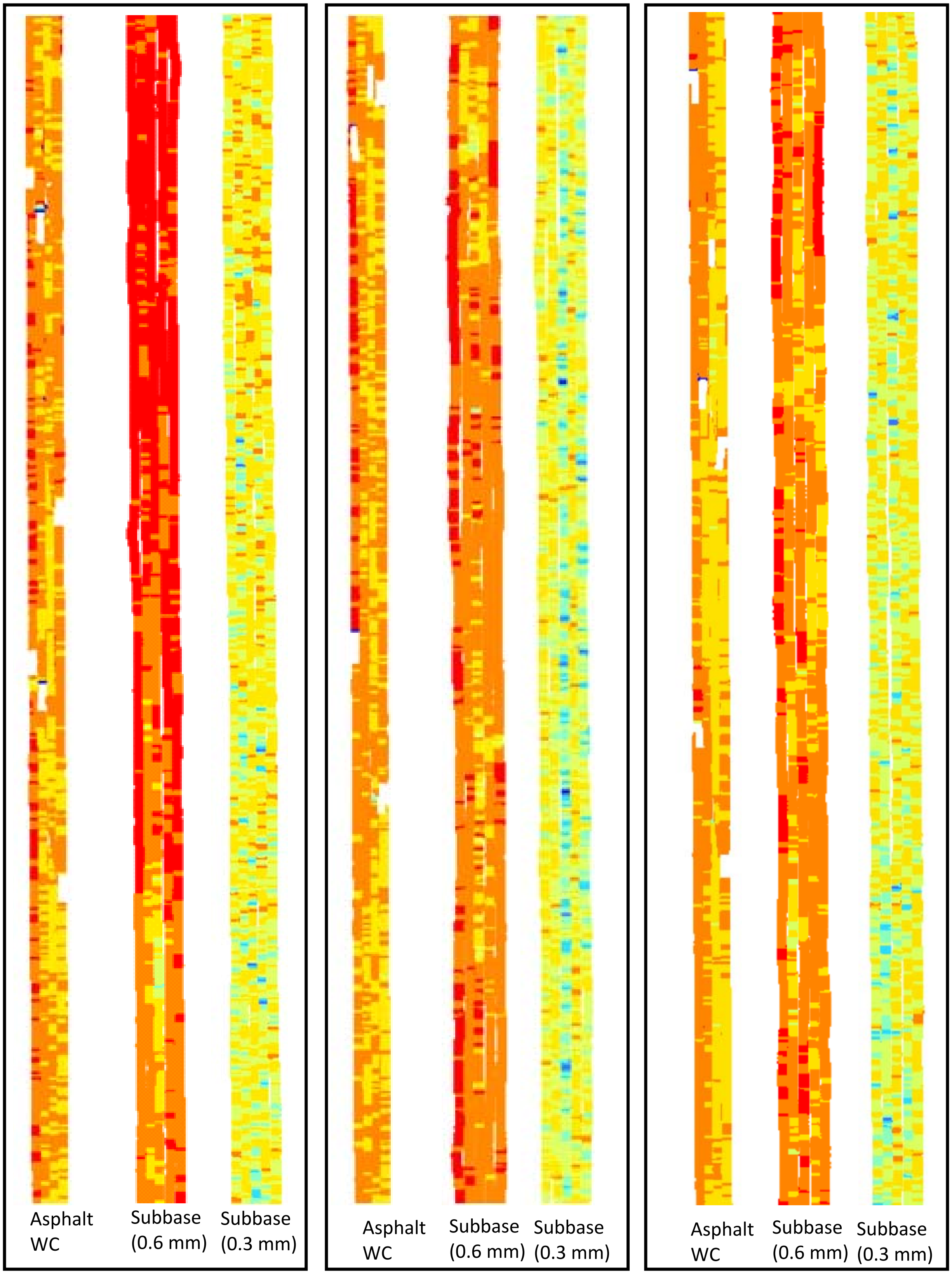
Overview of Soils Along Route 4, Kandiyohi County, Minnesota (NRCS 2008)

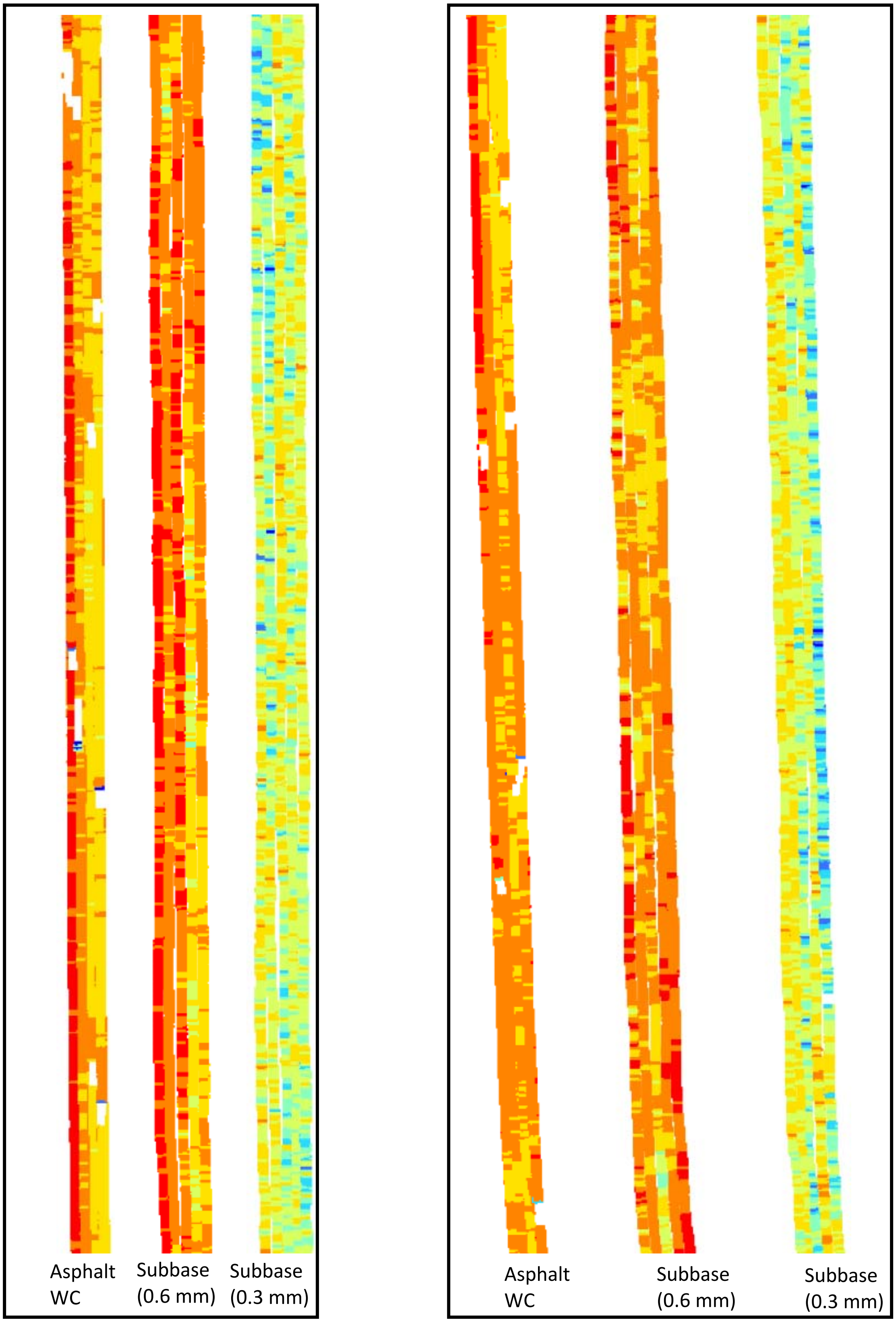
Map Unit	Name	Landform	Parent Material	Drainage Class	Water Table	Typical Profile
523	Houghton muck	Depressions on moraines	Muck herbaceous organic material	Very poorly drained	0 in.	0 to 60 in – Muck
875	Estherville-Hawick complex	Hills on outwash plains	Coarse-loamy outwash over sandy and gravelly outwash	Moderate to well drained	> 80 in.	0 to 12 in – Loamy coarse sand 12 to 60 in – Gravelly coarse sand
548	Palms muck, sandy substratum	Depressions on outwash plains	Muck herbaceous organic material over sandy outwash	Very poorly drained	0 in.	0 to 27 in – Muck 27 to 39 in – Sandy clay loam 39 to 60 in – Coarse sand
807	Koronis-Sunburg complex	Hills on moraines	Coarse-loamy till	Well drained	> 80 in.	0 to 8 in – Loam to sandy loam 8 to 60 in – Fine sand to sandy clay loam
805	Sunburg-Wadenill complex					
981	Canisteo-Harps loams	Flats on moraines, rims on depressions on moraines	Fine-loamy till	Poorly drained	6 to 18 in.	0 to 60 inches – Loam
113	Webster silty clay loam	Flats on moraines	Fine-loamy till	Poorly drained	6 to 18 in.	0 to 20 in – Silty clay loam 20 to 28 in – Clay loam 28 to 0 in – Clay loam
613	Grovecity loam	Rises on moraines	Coarse-loamy till	Moderately well drained	30 to 43 in.	0 to 16 in – Loam 16 to 60in – Fine sandy loam

APPENDIX B: CCV MAPS FOR SUBBASE AND HMA WEARING COURSE LAYERS


CCV
0 - 3
3 - 6
6 - 9
9 - 12
12 - 15
15 - 18
18 - 21
> 21
Asphalt Wearing Course (WC) Map, a = 0.6 mm f = 3000 vpm
Subbase Layer Map, a = 0.6 mm f = 2500 vpm
Subbase Layer Map, a = 0.3mm f = 3000 vpm
N
W
E
S
0 115230 460 690 920 1,150
Meters


Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)


Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)


Asphalt WC
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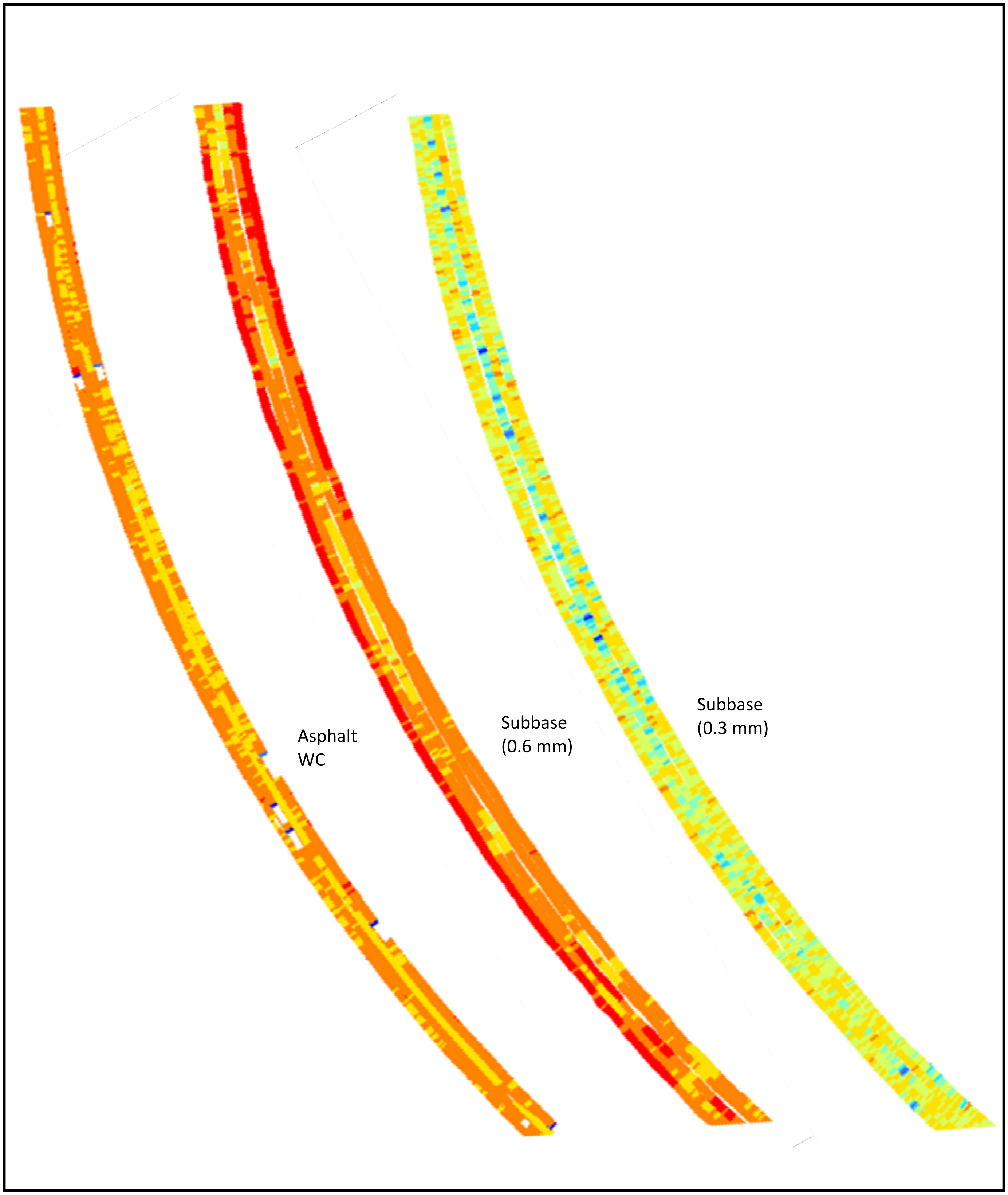
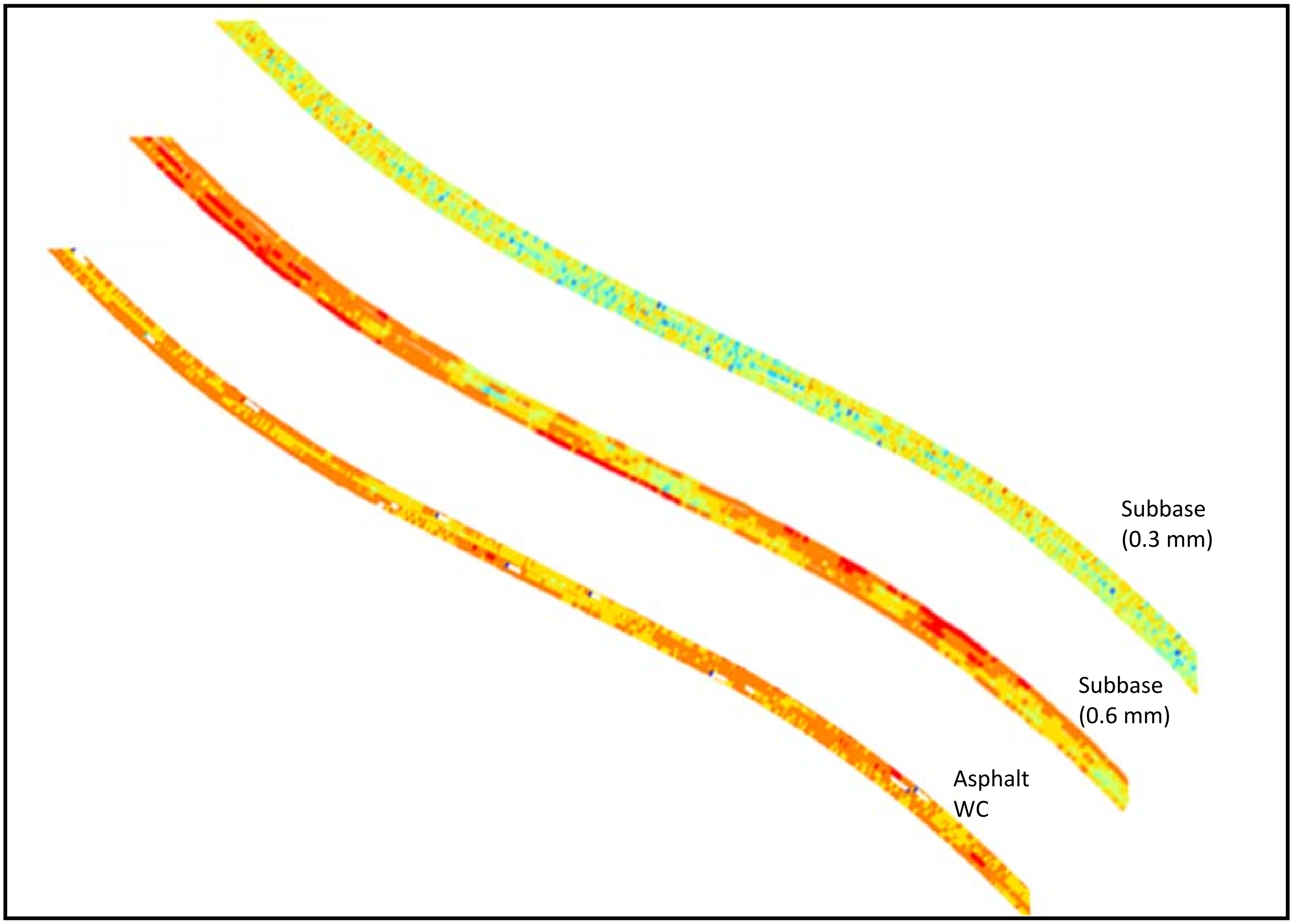
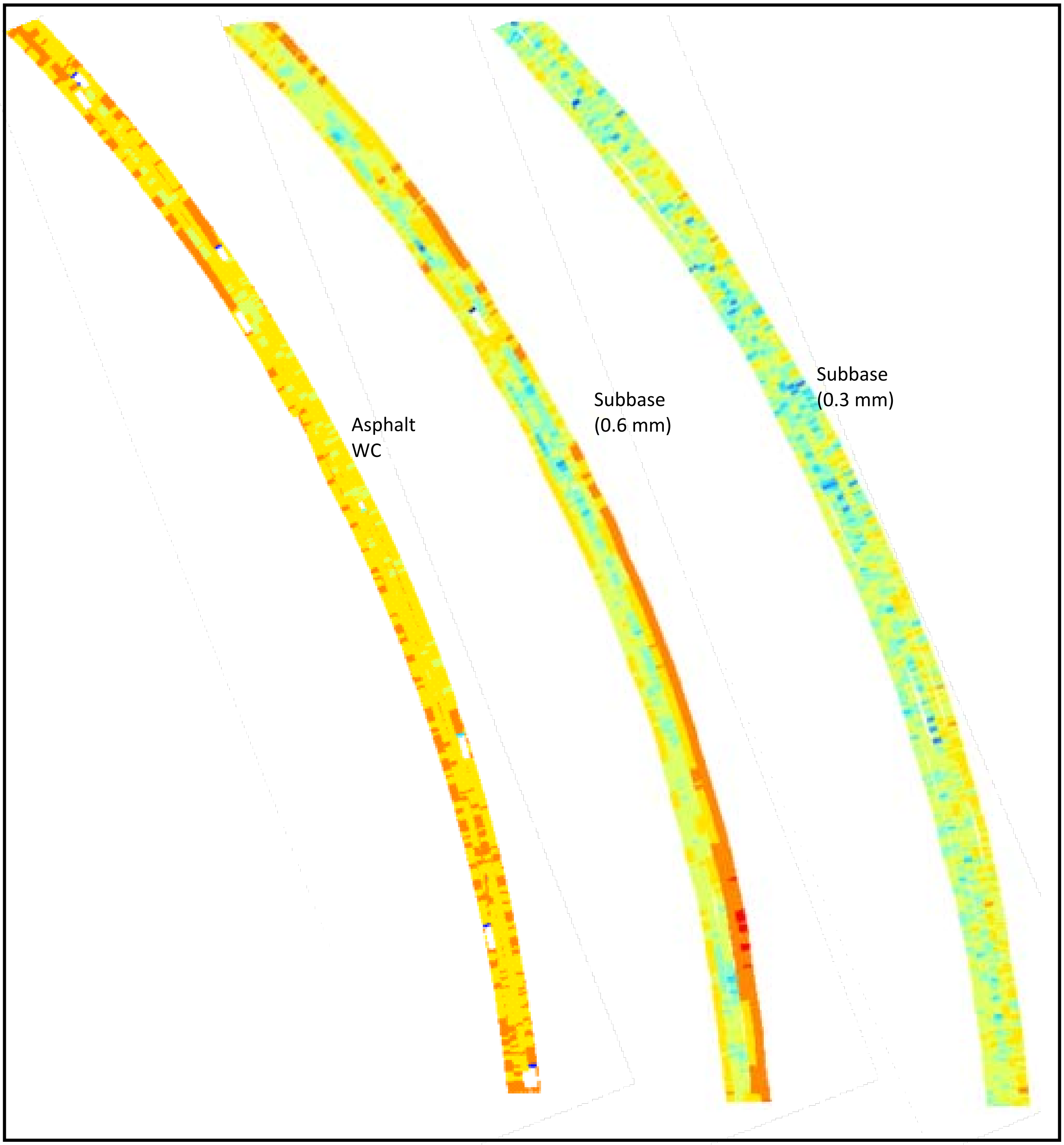
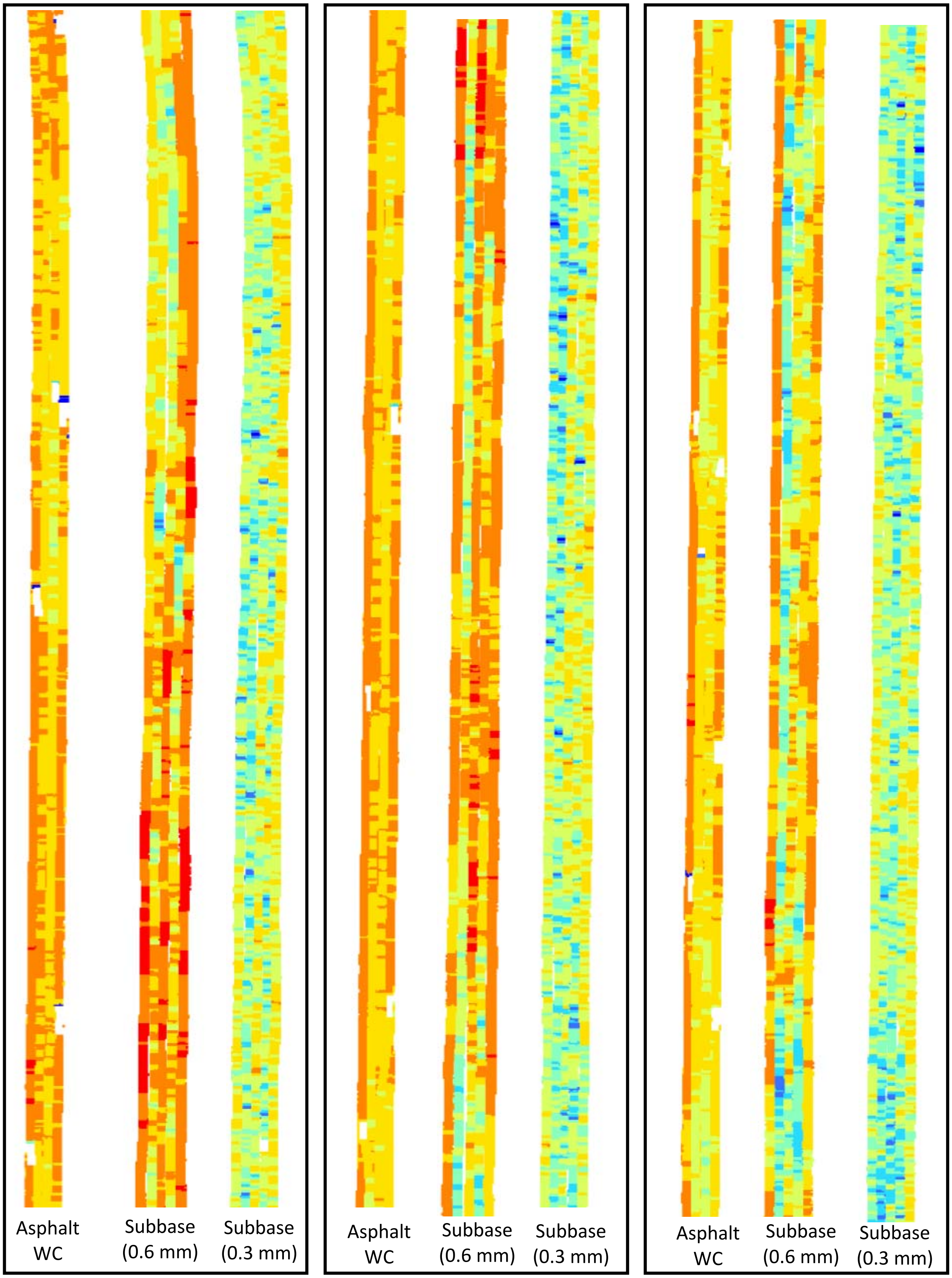
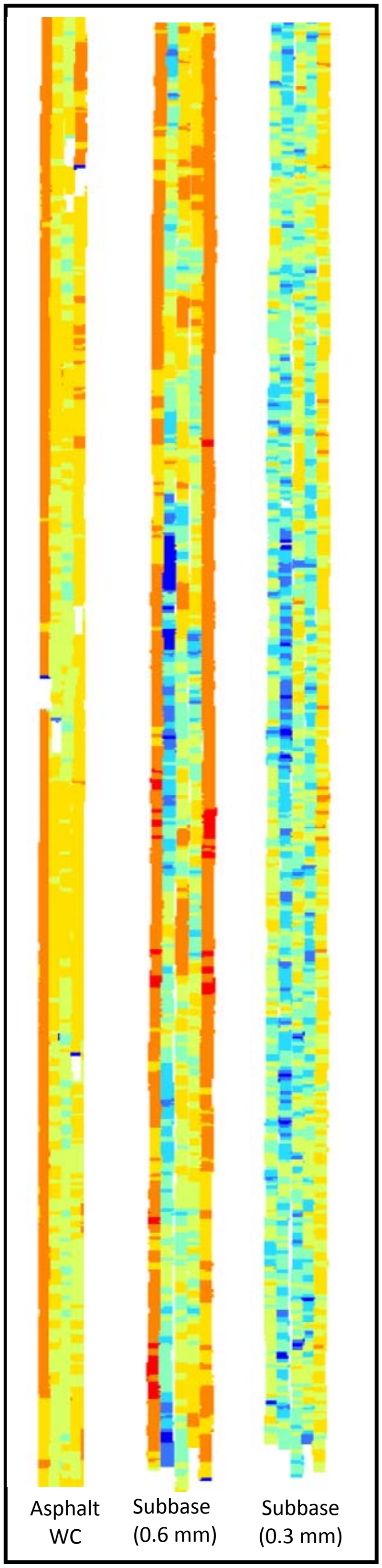
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)


Asphalt
WC
Subbase
(0.6 mm)
Subbase
(0.3 mm)


Subbase
(0.3 mm)
Subbase
(0.6 mm)
Asphalt
WC


Asphalt
WC
Subbase
(0.6 mm)
Subbase
(0.3 mm)


Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)
Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)


Asphalt WC
Subbase (0.6 mm)
Subbase (0.3 mm)