

Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287



Report – 3rd Quarter, 2021

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SUMMARY

We provide a progress report for the 3rd quarter of 2021. This report summarizes key topics regarding work in progress. After more than six months of renovation, the prime contractor website ([Park Seismic LLC](#)) has now reopened with all updated contents and structures. Details and supporting documents for this report have been posted on the [project web pages](#) created and maintained within the company website. The overall progress has been summarized by month and posted on the "[Progress](#)" page.

Due to the COVID pandemic, there has been a significant change and delay in work schedule and progress of the subcontractor (Norrfee Tech) during the last 1.5 years. The two (1st and 2nd) Joint Field Test (JFT) scheduled to take place in Lund, Sweden, was (will be) replaced by multiple remote sequential tests of hardware and software through a prolonged period (e.g., 6 months). In consequence, a contract amendment was submitted in August and approved by MnDOT that includes [new project schedule and budget](#). The new amended project schedule includes an extension of the project period from October 2021 to June 2022. It also includes a budget reallocation between labor and direct expenses without change in the total amount already granted.

Progress summary of the previous quarter (Q2-2021) was delivered to TAP members via email. This report summarizes the progress made since then for 5 tasks specified in the [Scope of Work \(SOW\)](#), namely:

- Task #1: Project Management and Administration
- Task #2: Hardware Development (Seismic Data Acquisition System) & Testing
- Task #3: Software Development & Testing
- Task #4: Delivery and Demonstration of Seismic Data Acquisition System and Software
- Task #5: Final Report

Progress on the first 3 tasks (#1 – #3) are summarized in this report. First, we provide brief snapshots of monthly progress that has been summarized in the [progress](#) web pages. Second, quantified indices are tabulated for all tasks for both prime (Park Seismic LLC) and sub (Norrfee Tech, AB) contractors. Lastly, we present projections for the next quarter (Q4-2021) by compiling feedback and plans from all project participants.

MONTHLY PROGRESS

[July 2021](#)

- **Project Management and Administration (Task #1)**

The proposed contract amendment has been submitted for approval on July 12, 2021. The 2nd quarterly report of 2021 (Q2-2021) was prepared and submitted to TAP members via email on July 17. The report can be downloaded from the website.

The [monthly meeting](#) was organized via Skype and the minutes were prepared by the administration staff. The monthly invoicing and payment to the sub-contractor has been managed

by the staff. The project web site has been updated a few times each month to reflect the progress status.

- **ParkSEIS-HMA (PS-HMA) GPS Display Module (Tasks #3)**

The GPS data display module in ParkSEIS-HMA (PS-HMA) software package has been under development. It is now complete up to the stage where it can display existing GPS data file in a chart of equal horizontal-vertical scale. It can also import an image (*.jpg) of Google satellite map in the background so that the displayed GPS data points can be overlapped. The mutual scales can be adjusted by using mouse panning and scroll zoom. An example display of the GPS data collected during the 1st Joint Field Test (1st JFT) executed during February 2021 is presented on the website.

[August 2021](#)

- **Project Management and Administration (Task #1)**

As of August 26, 2021, the requested contract amendment has been approved by the MnDOT Research Services Section. The new amended project schedule includes an extension of the project period from October 2021 to June 2022. It also includes a budget reallocation between labor and direct expenses without change in the total amount already granted.

The [monthly meeting](#) was organized via Skype and the minutes were prepared by the administration staff. The monthly invoicing and payment to the sub-contractor has been managed by the staff.

- **The 2nd Joint Field Test (JFT) Executed (August 31, 2021) (Tasks #2)**

The second joint field test of both hardware system developed at the Norrfee Tech (NT) and the software package developed at Park Seismic LLC (PS) has been conducted at the same location previously used for the 1st JFT performed on February 26, 2021. A short video clip recorded inside the survey vehicle is posted [here](#). The main purpose was to collect the data while the HMA pavement is at much higher temperatures than the 1st JFT so that the severity of seismic wave attenuation can be assessed. The average temperature during the 2nd JFT was about 33 degrees in Celsius, whereas it was about 7 degrees during the 1st JFT. Other secondary purposes included the accuracy evaluation of the GPS measurement by the hardware system and the overall reliability in the assessment of velocity (Vs) and thickness (H) by the PS-HMA package under "warm" temperature condition.

The results of velocity (Vs) and thickness (H) evaluation by the PS-HMA package are displayed on the website along with the temperature data. The corresponding results obtained during the 1st JFT are also displayed on the website for the comparison purposes. Although more data points were obtained during the 1st JFT (about 2000 points), results are displayed only for the first 320 points, the number of data points the 2nd JFT collected.

The velocity (Vs) results indicate the overall values are about 1300 m/s that is much lower than the value obtained during the 1st JFT (about 1800 m/s), conforming to the general notion that the HMA

pavement becomes "softer" when "warmer." It is noticeable, however, that the values highly fluctuate and the overall signal-to-noise ratio (S/N) values are much lower (e.g., 0.60) than the values during the 1st JFT (e.g., 0.99). It is believed this is due to the increased attenuation of seismic waves under warm temperature. In addition, those velocity values highly deviating from the average value (e.g., 500 m/s, 2000 m/s, etc.) have particularly lower S/N values (e.g., 0.40-0.50), while those close to the average value have relatively higher S/N values (e.g., 0.70-0.90). Display of only those velocity (V_s) values above a certain cut-off S/N value (e.g., > 0.70) will remove the "outliers" in the plot.

The thickness (H) results indicate the most common values are about 5 cm (70%) and others (30%) fluctuate between 5 cm and 15 cm. It seems there is also a correlation in S/N values between the most common thickness value (e.g., $S/N=0.80$) and those fluctuating ones (e.g., $S/N=0.40$). The 1st JFT results shows the most common value is about 10 cm with much lesser degree of fluctuation. As the thickness value should not change with temperature, one of the two values (i.e., 5 cm or 10 cm) should be a more accurate one. Considering the overall S/N values for the 1st JFT results are higher (e.g., 0.95) than for the 2nd JFT results (e.g., 0.50), $H=10$ cm seems a more accurate value. More detailed investigation is currently under execution.

Norrfee Tech (NT) is currently investigating the accuracy of GPS data and examining for possible delays in measurements. NT and Park Seismic (PS) are currently investigating what caused the "TDMS conversion error" that occurred when the number of records per TDMS (NRCD) exceeded ten (10).

More thorough analysis results of the 2nd JFT data will be available in the next month's progress page (i.e., Sept-2021).

- **ParkSEIS-HMA (PS-HMA) GPS Display Module (Tasks #3)**

The GPS data display module in the ParkSEIS-HMA (PS-HMA) software package has been under development for the last few months. It continued this month so that it can capture and import a Google map through a few simple steps. The "capture" module can save the map displayed on the screen as an image file (*.jpg) along with a distance scale and the location information (latitude and longitude) of a reference point on the map. Next stage of the development will import this saved file and display on the background of the current display of GPS data points.

[September 2021](#)

- **Project Management and Administration (Task #1)**

The [monthly meeting](#) was organized via Skype and the minutes were prepared by the administration staff. The monthly invoicing and payment to the sub-contractor has been managed by the staff.

- **Preliminary Analysis of Data Sets from the 2nd Joint Field Test (JFT) Executed on August 31, 2021 (Tasks #2 & #3)**

Norrfee Tech executed the second Joint Field Test (2nd JFT) on August 31, 2021, on the same road previously used for the 1st JFT executed in February 2021. The main purpose was to compare the quality of Lamb waves collected under relatively warm temperature to the quality at lower temperature. The measured average temperature along about 100-m long road was 33 C, while it was 7 C during the 1st JFT. Other purposes included a field test of GPS measurement in the PXI system and the pseudo-real-time TDMS data conversion of the ParkSEIS-HMA (PS-HMA) software. Occasional delayed GPS measurements were observed on the first day, and the issues were resolved from further field tests on the following days by Norrfee Tech. The software issues in the transfer of TDMS files were also identified during both lab and field tests. They were subsequently resolved through mutual communication between Norrfee Tech and Park Seismic as well as algorithmic modifications in PS-HMA.

In this [report](#), preliminary analysis results are presented in comparison to those from the 1st JFT. They are compared in the evaluation results of seismic velocity (V_s) and thickness (H) of the pavement. The 2nd JFT results are presented first, and then those from the 1st JFT are presented. They are compared in the consistency of the values (V_s and H) along the surveyed distance of pavement. Their overall signal-to-noise (SN) ratios are also compared.

The average velocities (V_s) are observed at about 1300 m/s, which is lower than those observed at lower temperatures during the 1st JFT (e.g., 1800 m/s). However, the overall SN ratios are observed about 50%, while it was above 95% for the 1st JFT. It is believed this significant difference in S/N originated from the severe attenuation of seismic waves at the high temperature. The average thicknesses (H) are observed at about 5 cm, which is significantly different than those from the 1st JFT (e.g., 10 cm). Considering the lower overall S/N, the values from the 1st JFT are believed more reliable.

Results of the attenuation analyses for both 1st and 2nd JFT data sets are also presented in the [report](#).

- **ParkSEIS-HMA GPS Display Module (Tasks #3)**

The GPS data display module in the ParkSEIS-HMA (PS-HMA) software package has been under development for the last few months. It continued this month so that it can capture and import a Google map through a few simple steps. The "capture" module (see a screenshot displayed on the website) can save the map displayed on the screen as an image file (*.jpg) along with a distance scale and the location information (latitude and longitude) of a reference point on the map. Then, the GPS data display module (see a screenshot displayed on the website) can import the saved file and display the map on the background of the current display of GPS data points. The GPS data display module has options to pan and zoom both background image and displayed GPS data.

PROGRESS BY TASKS AND NUMBERS

The entire work executed to accomplish the project goal is categorized into five (5) tasks (Tasks #1 – #5) as previously listed. In this report, the progress accomplishments made by both prime and sub contractors are described in all five (5) tasks (#1 – #5) by using the quantified indices used in the progress report form (Exhibit E-1 in the amended project contract) submitted each month. These values are presented in tables on this page and then graphically displayed in the next page.

Work Completed – Prime* & Sub** Contractors

This Period (%)

Task	Previous Quarter (Q2-021)			This Quarter (Q3-021)		
	April	May	June	July	August	September
#1	5.7	6.0	3.0	5.7	1.3	1.3
#2	0.9	3.0	2.1	1.3	2.7	1.7
#3	2.4	1.3	3.3	2.4	3.4	0.0
#4	0.0	0.0	0.0	0.0	0.0	25.0 ⁺
#5	0.0	0.0	0.0	0.0	1.8 ⁺	0.0

To Date (%)

Task	Previous Quarter (Q2-021)			This Quarter (Q3-021)		
	April	May	June	July	August	September
#1	101.7***	107.7***	110.7***	116.3***	111.0***	112.3***
#2	77.3	80.3	82.4	83.7	85.8	87.5
#3	72.2	73.6	76.9	79.3	76.6	76.6
#4	0.0	0.0	0.0	0.0	0.0	25.0 ⁺
#5	0.0	0.0	0.0	0.0	1.8 ⁺	1.8 ⁺

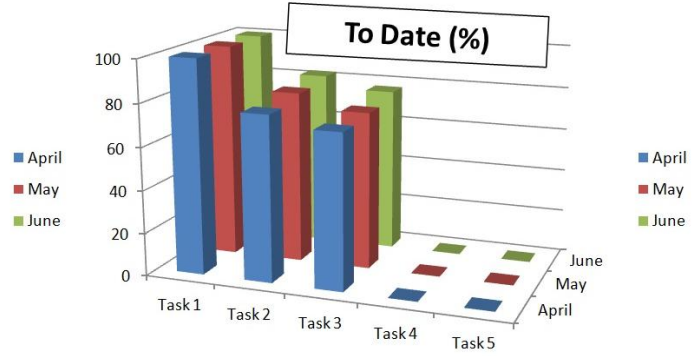
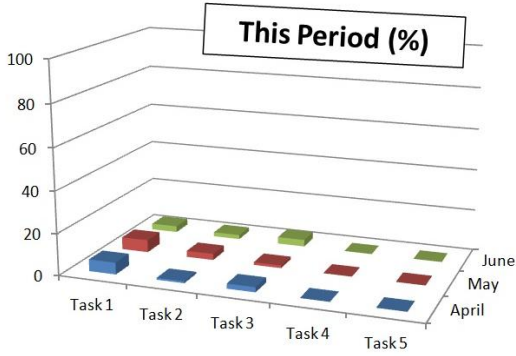
*Park Seismic LLC, **Norrfee Tech, AB

***More admin hours have been used than originally anticipated. These hours are being substituted by unused hours in tasks #4 and #5. This type of mutual adjustment in actual task hours will be made accordingly as the project execution continues.

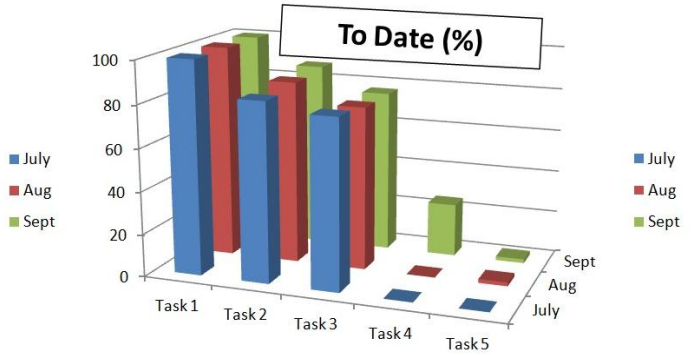
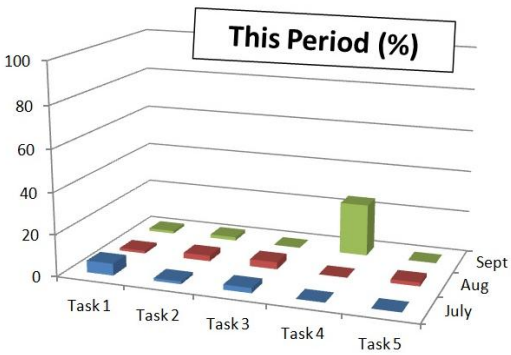
⁺Reassigned hours of task #1 as all allocated hours are consumed (i.e., ≥ 100%).

Progress (Prime & Sub Contractors Combined)

Previous (2nd) Quarter (April – June 2021)



This (3rd) Quarter (July – September 2021)



PROJECT PROJECTION

Projections made in the three tasks (#1 – #3) for the next three months (Q4-2021) are summarized below.

- **Task #1: Project Management and Administration**

As no international travels are planned according to the amended project schedule, the original 2nd Joint Field Test (JFT) will continue and be further accomplished by a series of field test at Norrfee Tech (Lund, Sweden). In addition, as travel-related funds have been reallocated for more labor hours, the new invoice (Exhibit D-1) and progress report (Exhibit E-1) forms will be used for the monthly invoicing package whenever submitted. As all admin hours (task #1) have been consumed (and the amended contract failed to account for this when prepared), future admin hours will have to be reported under different tasks (e.g., #4 and #5).

- **Task #2: Completion of 2D Hardware System**

Norrfee Tech will build the 2D system by adding three (3) more identical 1D microphone arrays according to the scheme proposed during the [project update presentation](#) on May 18 (the diagram appears after 36:27 timeline in the video). The lateral spacing between the successive 1D arrays ('dY' in the diagram) depends on the maximum source distance ('dX') that can be maintained without encountering the issue of severe Lamb-wave attenuation at high temperatures (e.g., ≥ 30 °C). As the results from the 2nd JFT executed during August and September indicated the current $dX=15$ cm can still generate analyzable Lamb waves at 33 °C, it seems this (15 cm) will likely be the minimum value of dX, which will allow $dY \approx 30$ cm. Then, the 2D system will cover a 4-ft width of pavement, at minimum, simultaneously during the survey. Considering the dX can be further extended (e.g., $dX=30$ cm) when pavement temperature is relatively low (e.g., ≤ 10 °C), the 2D-array frame will be adjustable so that its lateral coverage can be extended accordingly as can be depicted from the diagram.

Norrfee Tech plans to complete and deliver the system by the end of the year 2021 so that Park Seismic LLC can use it for field tests to help optimize the software package currently under development.

- **Task #3: Software Development & Testing**

The ParkSEIS-HMA software package (PS-HMA) will complete the GPS display module during the early part of the next quarter. It will then develop the velocity (V_s) and thickness (H) analysis modules for the 2D arrays. Considering that the pseudo-real-time in-field analysis of 2D data sets will require significant CPU time, various types of data resampling options will be considered and tested during the development. The optimum modes to display 2D results from multiple receiver arrays will be developed. The prototype version will be available before the completed 2D hardware system is delivered to Park Seismic LLC (e.g., by the end of year 2021). Then, the entire software package will go through the final calibration and refinement stages by executing multiple field tests with the delivered hardware system during the early several months of year 2022 (e.g., Jan-Apr).