Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287

Report – 4th Quarter, 2021

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SUMMARY

We provide a progress report for the 4th quarter of 2021, the final quarterly report. According to the amended project schedule, the next report will be the final report due in June 2022. This report summarizes key topics regarding work in progress during this quarterly period. Since the sub contractor (Norrfee Tech, AB) completed its main task of building and testing the field data acquisition system in mid January 2022, the reporting period extends a few more weeks after December 2021. Details and supporting documents for this report have been posted on the project web pages created and maintained within the prime contractor website (Park Seismic LLC). The overall progress has been summarized by month and posted on the "Progress" page.

As of January 2022, Norrfee Tech completed building the final 2D 64-channel field data acquisition that consists of four (4) MEMS microphone arrays (16 channels per array) with each array arranged transversely with a 0.2-m separation. The Joint Field Test with this completed system (JFT-2D) performed on January 10, 2022, successfully demonstrated a seamless data acquisition over about 1800-m asphalt road by making measurements at about 3,600 longitudinal points along the survey line (i.e., approximately 2 longitudinal measurements per meter). The on-board ParkSEIS-HMA (PS-HMA) software package demonstrated a successful pseudo-real-time data handling of the collected data. The post-acquisition process by PS-HMA took about 4 hours to automatically analyze all 14,400 sampled points (4x3,600) and generated planview maps of velocity (Vs), thickness (H), and corresponding signal-to-noise (S/N) values for the surveyed 0.8 m x 1,800 m area of the road. More details are posted in the December progress page. The system is currently under preparation for shipping to Park Seismic LLC where it will be used for further development of the PS-HMA software package as well as for the impact source characterization purposes.

Progress summary of the previous quarter (Q3-2021) 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 made on all 5 tasks (#1-#5) for the remainder of the project period (January-June 2022).

MONTHLY PROGRESS

October 2021

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

The Park Seismic LLC web site has been under upgrade renovation since March 2021. It was an unavoidable change because of the discontinuation at the end of February 2021 of the old web-build platform that used to be supported by the web-hosting company (Yahoo). All project contents had been internally updated and saved every month since March. They have been now posted on the corresponding project web pages as of October 2021.

Based on the amended project contract approved in August 2021, the travel-related funds had been reallocated for more labor hours. In consequence, the new invoice (Exhibit D-1) and progress report (Exhibit E-1) forms are now used for the monthly invoicing package whenever submitted. In addition, as all admin hours (task #1) have been consumed (and the amended contract failed to account for this when prepared), admin hours are now being reported under different tasks (e.g., #4 and #5).

The third quarterly report of 2021 was submitted on October 29, 2021. 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 once a month to reflect the progress status.

- **2D System Being Built at Norrfee Tech (Tasks #2)**

Norrfee Tech started wiring for the 2D system that consist of a 64-channel AD converter and four (4) of 16-channel microphone arrays. It also started designing the frame to be harnessed on a bicycle rack that will hold the four-receiver arrays and one common impact source. The frame will allow each 16-channel array to be adjusted in its location along a dedicated rod, four of which will be radially arranged on the frame with the impact point located at the origin. The current design of the frame aims at a maximum 5-ft lateral (transverse) range that all four arrays can survey simultaneously.

- **ParkSEIS-HMA | GPS Display and Velocity (Vs) - Thickness (H) Evaluation Modules (Tasks #3)**

The GPS display module has been under modification to improve the accuracy in the match between the measured GPS data points and imported Google map image displayed on the background. Another mode to import a map image has been added to improve the resolution of the display and also the accuracy in the match. It can now import a high-resolution (e.g., 4,800 x 2,645) satellite map created by using Google Earth Pro.

Velocity (Vs) and thickness (H) evaluation module has been modified to improve the overall accuracy and consistency. Previously, the signal-enhancement method that utilizes the lateral (along the longitudinal direction) stacking of constructed dispersion images could be applied only within the records contained in one TDMS file (e.g., 10 records). In consequence, the signal enhancement significantly degraded for those records collected at the beginning and ending portions, respectively, of one TDMS file. This was due to the limited number of previous and next records, respectively, available for the stacking. This used to cause apparent discontinuities in the display of evaluated Vs and H values at the points where a new TDMS file begins.

This has been modified. A global dispersion image is now continuously constructed as multiple TDMS files are processed. The signal-enhancement process is then applied to this global image so

that the number of stacking can remain unchanged for all records. This eliminates the apparent discontinuities.

November 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. The project web site has been updated once a month to reflect the progress status.

- **2D System Under Construction at Norrfee Tech (Tasks #2)**

  Construction of 2D arrays consisting of four (4) 16-channel arrays is under execution at Norrfee Tech. Construction of the array holding frame to be harnessed at the bottom of the bicycle rack is also under execution.

- **ParkSEIS-HMA | 2D Data Process Module and Visualization Module (Tasks #3)**

  The process module has been constructed that imports 2D data in 64-channel TDMS files. The module separates a TDMS data file into four subsets of 16-channel data, each of which is processed separately to generate its own results of velocity (Vs) and thickness (H) information. The visualization module is under construction and has been built up to the point where 1D results from the four arrays are independently displayed on the same chart as illustrated in the web page. The module will include a separate visualization window to display 2D planview maps for Vs and H results that will be constructed in a pseudo-real time mode as data are continuously acquired.

- **Velocity (Vs) and Thickness (H) Evaluation of 1st and 2nd JFT Data Sets (Tasks #3)**

  The field data sets collected during the 1st (February 23, 2021) and 2nd (August 31, 2021) Joint Field Test (JFT) are revisited to evaluate the average shear-wave velocity (Vs) and thickness (H) of the pavement. The average temperature of the pavement was 7 degrees and 33 degrees in Celsius during the 1st and 2nd JFT's, respectively. The main purpose of the revisit is to come up with the most reliable estimations for Vs and H for the same road surveyed at significantly different temperatures. More details are presented in this report.

December 2021-January 2022

- **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. The project web site has been updated once a month to reflect the progress status.

- **2D System Completed and Joint Field Test (JFT-2D) Performed (Tasks #2 & #3)**

  On January 10, 2022, Norrfee Tech performed the Joint Field Test (JFT-2D) by using the completed 2D data acquisition system. More details about the system and field operation are presented in another presentation file ("Analysis220110b.pdf") and video files prepared by Norrfee Tech. More selected video files will be posted on YouTube in the near future. Survey photos and a sample data are presented in Figure 1 of the corresponding web page.

  The JFT-2D proceeded over approximately 1800-m long asphalt road that included the segment previously used for JFT's with 1D system. The test collected a total of 185 TDMS files, each of which contained 20 measurement records (except for the last file that contained only 3 records). A total of 3,683 measurements were made, which gives an approximate rate of 2 measurements per meter or one measurement every half meter. One measurement record contains a 64-channel 5-ms recording data from four (4) MEMS microphone arrays (i.e., channels 1-16 for array#1, 17-32 for array#2, 33-48 for array#3, and 49-64 for array#4) arranged transversely with a 0.2-m separation.

  The system is currently under preparation for shipping to Park Seismic where it will be used for further in-house tests to improve the performance of the entire system (i.e., hardware and software).

- **ParkSEIS-HMA | Test with JFT-2D Data (Tasks #3)**

  During the JFT-2D operation, Norrfee Tech also tested some key features of the ParkSEIS-HMA (PS-HMA) software package that are related to the 2D data handling (e.g., ARM, DISARM, STOP, real-time TDMS copy and conversion, real-time process and visualization of 2D results, etc.). The on-site analysis of all acquired (185) TDMS files could not be finished because of the excessive process time (e.g., hours). Instead, all files were processed afterward in the Park Seismic office by simulating the field measurement (i.e., manually feeding TDMS files to PS-HMA software). It took about four (4) hours to finish the entire data process and visualization of the results that proceeded in a full-automatic mode. In this report file, all results obtained and visualized by the PS-HMA software are presented. The selected 2D results are displayed in Figure 2 of the web page.

  All these data files are currently being used to improve the overall performance (i.e., accuracy and speed) of the analysis and visualization modules of the PS-HMA software.

- **ParkSEIS-HMA | Velocity (Vs) and Thickness (H) Evaluation - Accuracy Assessment (Tasks #3)**

  The velocity (Vs) and thickness (H) evaluation algorithm incorporated in the ParkSEIS-HMA package is systematically tested on modeling data sets. The algorithm was briefly explained in one of the previous reports posted online. The main purpose of the test is to assess the accuracy of the algorithm. Using the reflectivity method, seismic records are modeled based on a specific layer model that consists of velocity (Vs) and thickness (H) of typical pavement structure (i.e., pavement layer, base, and subgrade). Vs and H of the top pavement layer are controlled to generate testing seismic records.

  Each modeled seismic record is processed by ParkSEIS-HMA package to evaluate Vs and H that are then compared to the "true" values. First, 11 records are modeled for a given thickness (H=10 cm) at 11 arbitrarily different velocities (1,000 m/s <= Vs <= 2,000 m/s). Second, 10 records are

modeled for a given velocity (Vs=1,000 m/s) at 10 arbitrarily different thicknesses (6 cm <= H <= 15 cm). Third, 10 records are modeled for a given velocity (Vs=1,500 m/s) at 10 different thicknesses (6 cm <= H <= 15 cm). Fourth, 10 records are modeled for a given velocity (Vs=2,000 m/s) at 10 different thicknesses (6 cm <= H <= 15 cm). In this way, a total of 41 records are modeled. All these records are then transformed to dispersion images, to each of which the ParkSEIS-HMA package was applied to evaluate corresponding velocity (Vs) and thickness (H) values. All evaluated values of Vs and H are tabulated along with true values used for the modeling. Relative errors (%) are calculated to assess the accuracy of the algorithm. One example of the calculated errors is displayed in Figure 3 of the web page. The average errors for velocity (Vs) and thickness (H) evaluations are calculated as 3.89% and 11.48%, respectively. All these procedures are graphically illustrated in this report.

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 (Q3-021)			This Quarter (Q4-021)		
	July	August	September	October	November	December
#1	5.7	1.3	1.3	1.3	0	0
#2	1.3	2.7	1.7	2.6	5.5	1.8
#3	2.4	3.4	0.0	2.8	4.4	1.1
#4	0.0	0.0	25.0^{+}	11.9^{++}	11.9^{++}	52.4^{++}
#5	0.0	1.8^{+}	0.0	3.5^{++}	2.6^{++}	21.1^{++}

To Date (%)

Task	Previous Quarter (Q3-021)			This Quarter (Q4-021)		
	July	August	September	October	November	December
#1	116.3***	111.0***	112.3***	113.5	113.5	113.5
#2	83.7	85.8	87.5	90.1	95.6	97.4
#3	79.3	76.6	76.6	79.3	83.7	84.8
#4	0.0	0.0	25.0^{+}	36.9^{++}	48.8^{++}	101.2^{++}
#5	0.0	1.8^{+}	1.8^{+}	5.3^{++}	7.9^{++}	28.9^{++}

**Park Seismic LLC, **Norrfee Tech, AB*

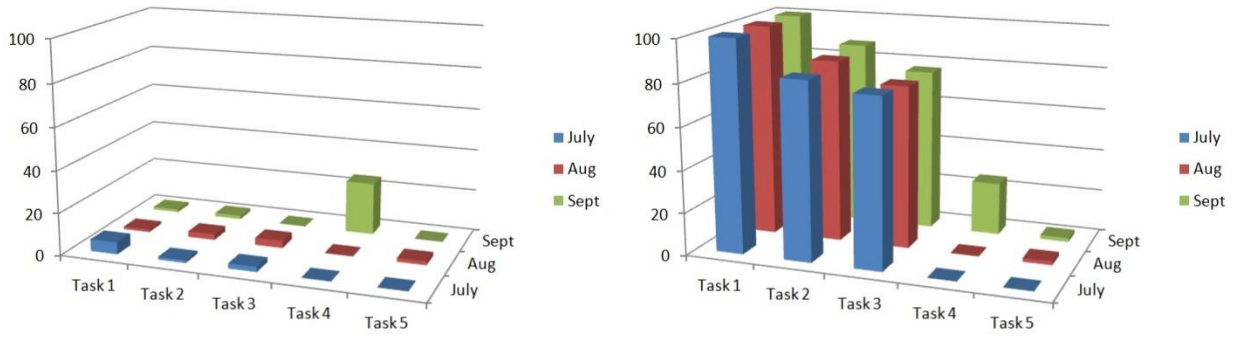
****More admin hours have been used than originally anticipated. These hours are being substituted by unused hours in tasks #4 and #5. This type of mutual adjustment in actual task hours has been made accordingly as the project execution continued.*

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

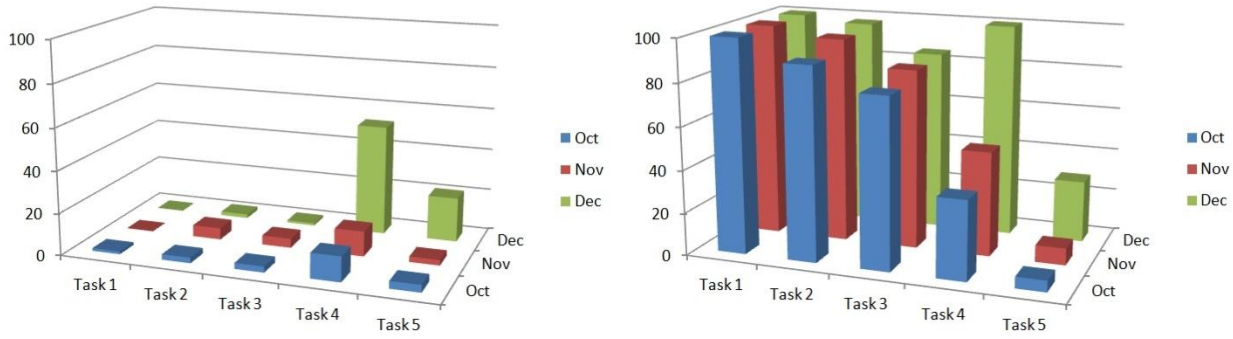
$^{++}$Includes reassigned hours of task #1.

Progress (Prime & Sub Contractors Combined)

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



This (4th) Quarter (October – December 2021)



PROJECT PROJECTION

Projections made in all tasks (#1 – #5) for the remainder of the project period (January-June 2022) are summarized below.

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

  According to the amended project schedule, there will be no more monthly meetings to take place. Instead, ad-hoc meetings will be arranged among the project participants whenever necessary. The "Progress" webpage will also be updated only when deemed necessary. The task of monthly invoicing will proceed in the same way.

- **Task #2: Hardware Development (Seismic Data Acquisition System) & Testing**

  No further major development of the system will be made. Instead, minor modifications and improvements may take place at Park Seismic LLC that can provide an enhanced level of convenience in the use, shipping, and storage of the system. They may also include minor changes in the array/impact source configuration to improve the Lamb-wave spectral characterizations.

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

  The ParkSEIS-HMA (PS-HMA) package will continue to be updated and developed in both data analysis and visualization modules through multiple field surveys by using the completed acquisition system. The main emphasis will be how to increase the accuracy and speed in velocity (Vs) and thickness (H) evaluation algorithms. The visualization modules will also be revisited and improved/modified if necessary in the intuitiveness of the result presentations. A separate module will be added that can export the result data sets of velocity (Vs) thickness (H) in various different formats.

  For the field testing purposes, a secure and well-controlled test site will be necessary near Park Seismic LLC (e.g., CT or NY).

- **Task #4: Delivery and Demonstration of Seismic Data Acquisition System and Software**

  Delivery of the complete acquisition system and software package will be made in June 2022 before the demonstration, which can possibly take place during the NRRA annual conference.

- **Task #5: Final Report**

  The final report will be submitted soon after the demonstration of the completed system and software package (#4). It is currently scheduled to be submitted in late June 2022.