Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287

Report – 3rd Quarter, 2020

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October 20, 2020

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SUMMARY

We provide a progress report for the 3rd quarter of 2020. This report summarizes key topics regarding work in progress. Details and supporting documents can be found on the project website. The overall progress has been summarized by month and has also been posted on the "Progress" page of the project site.

Progress summary of the previous quarter (Q2-2020) was presented in the report posted online. 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. Second, quantified indices are tabulated for all three tasks for both prime (Park Seismic LLC) and sub (Norrfee Tech, AB) contractors. Lastly, projections for the next quarter (Q4-2020) are prepared by compiling feedback and plans from all participants.

MONTHLY PROGRESS

July, 2020

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

  The 2nd quarterly report (Q2-2020) was prepared and submitted by all (4) project participants. It was posted on the web page in the form of a report.

  The monthly meeting was organized via Skype and the minutes were posted on the web page 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.

- **Field Data from Newly Constructed Asphalt Road, Lund, Sweden (July 22, 2020) (Task #2)**

  Field data sets acquired on July 22, 2020, on a newly constructed asphalt pavement near Lund, Sweden, are processed and evaluated for various purposes. The data sets were collected by using the old system ("SYS-RYD-2019"). The overall data quality is evaluated as "excellent" from raw field records and corresponding dispersion images that clearly show well-developed Lamb wave arrivals and the fundamental-mode anti-symmetric Lamb dispersion (A0), respectively. Here is one of the several hundred records obtained (> 500) in the field (left) and corresponding dispersion image and other spectral characteristics (right). Approximate inversion results obtained from Norrfee Tech show velocity (Vs = 1400 m/s), thickness (H = 0.1 m), and Poisson's ratio (POS = 0.3).

- **Further Testing of Air-Wave Alleviating Techniques (Task #3)**

  Testing of various multichannel techniques previously tested/developed that can alleviate adverse influence of air waves on the target analyses (i.e., Lamb and Impact Echo analyses) are tested for ten (10) randomly selected records from the data set on July 22, 2020. Three previously developed techniques are tested that can alleviate the air-wave energy as much as possible without compromising other useful attributes of obtained wavefields [e.g., wavefields for Lamb and Impact Echo (IE) analyses]. They are surgical mute (MUTE), fk-filter (FK), and air-wave subtraction by using moving-window LMO stack (AIR-SUBTRACTED). This report contains more details.

- **Quality Control (QC) Parameters (Task #3)**

  Testing of several quality control parameters for a particular type of wave (e.g., air or Lamb waves) such as overall amplitude ("Amp"), arrival time in ms ["msT0 (ms)"], velocity [e.g., "Vair (m/s)"], and peak frequency ["Fpeak (kHz)"] is performed by using the aforementioned ten (10) field record. This report contains more details.

- **TDMS Data Format (Task #3)**

  A project to build a C++ module to read the TDMS file of seismic data saved by the acquisition system being developed at Norrfee Tech was launched as of June, 2020. The project will complete a separate C++ program that reads TDMS files and converts them into the ParkSEIS data format, which is the standard format for the software package being developed. It seems necessary to use some library files provided by National Instrument (NI) for some functions to work properly within the C++ codes. This project is about to finish.

August, 2020

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

  The monthly meeting was organized via Skype and the minutes were posted on the web page by the administrative staff. Monthly invoicing and payment to the sub-contractor has been managed by the staff. The project web site has been updated each month to reflect progress.

- **Muting Air and Pre-Lamb Wavefields (Task #3)**

  The importance of properly alleviating air wave energy existing in an acquired raw field record has been addressed multiple times in the previous work reports (e.g., April, May, and July progress reports). This report summarizes outcomes from one of those approaches when applied to a field data set acquired on August 12, 2020, on the same road previously surveyed (see here for previous survey results). Among multiple approaches, It is the "mute" approach summarized in this report that erases (i.e., zeros) all wavefields outside a designated mute window in a time-offset display of a raw field record. It turned out to be the most effective when constructing an accurate Lamb dispersion trend. It is also important to apply a pre-Lamb mute to reduce harmful influence from ambient noise. Therefore, both air-wave mute and pre-Lamb mute are simultaneously applied to the raw field record. Three (3) different types of mute have been tested. One is called "MANUAL Mute" that sets the mute window by visually inspecting the record to identify air-wave and Lamb-wave arrival times (msT0-air and msT0-Lamb) and propagating velocities (V-air and V-Lamb). With this approach, each record is manually muted one by one. The other type is called "SURGICAL Mute" that sets the mute window semi-automatically based on the presumptive values for msT0-air, msT0-Lamb, V-air, and V-Lamb. The arrival times (msT0-air and msT0-Lamb) can be approximately estimated based on the acquisition parameter of pre-trigger time (e.g., 1.0 ms), which is the length of previous time after air waves triggered the recording and therefore should be included in the acquired record. The velocity values (V-air and V-Lamb) can be set arbitrarily based on a common range of each type of waves (e.g., V-air = 340 m/s and V-Lamb = 1500 m/s). Once these values are set, then the "SURGICAL Mute" applies the same mute window to all records existing in the input file automatically. The last type is called "AUTO Mute" that tries to detect all four parameters (i.e., msT0-air, msT0-Lamb, V-air and V-Lamb) automatically through its own detecting algorithm. The algorithm is based on the Linear-Move-Out (LMO) stacking to detect different waves (e.g., air vs. Lamb) arriving with different velocities. The "AUTO Mute" includes additional algorithms that can detect other wave attributes that may exist in the raw field record such as reverberating air wave arrivals, air wave arrivals from the opposite end of the receiver array, too-low signal-to-noise (SN) ratio, etc. They are automatically applied whenever detected being necessary to improve the accuracy in the evaluation of the mute window and also to improve the overall SN ratio of the recorded Lamb waves.

All three (3) approaches are applied to a data set acquired on August 12, 2020, on the same road previously surveyed on July 22, 2020. Results of time-domain records and corresponding dispersion images are displayed in this report for various comparison purposes in this report. Results from all three approaches are comparable to each other in seismic data and dispersion image qualities. However, the "AUTO Mute" provided slightly superior quality. The comparison will continue to be made on further future data sets to confirm the superiority. Advantage of pre-Lamb mute is illustrated in this report by using a field record that shows dispersion image trend at high frequencies (e.g., > 20 kHz) is improved due to the attenuation of ambient noise in the corresponding high frequency range.

Importance of using a "proper" mute window is also illustrated in this report by using a field record.

- **Data Acquired on August 12, 2020 (Task #2 & Task #3)**

All (20) field records acquired on August 12, 2020, are displayed in this report in raw data format as well as processed dispersion image format for the purpose of evaluating Lamb wave quality. They were obtained by using both forward (FWRD) and reverse (REVS) impact sources attached at forward (i.e., #1 channel side) and reverse (i.e., #48 channel side) side of the receiver array, respectively (watch the video below). All reverse-shot records, however, are purposely flipped to look like forward-shot records by the software at the time of data import, which is necessary to apply all mute approaches properly. In consequence, those reverse-shot records are separately marked by (*) to indicate so.

Comparing dispersion images from forward- and reverse-shot records, those from the reverse shots did not have proper Lamb dispersion trend as shown in this report. This seems to be related to a short pre-trigger time (0.5 ms) that was not long enough to catch the Lamb waves that arrived earlier than air waves by more than 0.5 ms (e.g., 1.0 ms) due to the extended distance between the array center and the impact point of the reverse shot. This will be verified from a next field survey with a longer pre-trigger time (e.g., 1.5 ms). This hypothesis was tested in two slides by using rough estimation of impact distances for both shots (i.e., FWARD and REVE) from the receiver array by using a configuration shown on a photo.

Amplitudes of forward and reverse shots are compared by displaying peak amplitudes of all (48) traces in each record in this report. The display indicates that, in general, the reverse shots were more powerful than the forward shots.

Decimation of channels (i.e., from 48 to 16 channels) was tested for each record from surveys performed during July and August for the purpose of evaluating any possible degrade of data quality in Lamb dispersion image. The results shown in this report indicate there is little difference, indicating that a 16-channel array will be able to provide an equally good quality.

- **TDMS Data Format (Task #3)**

A separate project to make a C++ module to import a TDMS data file and convert into a ParkSEIS (PS) data file has been launched in mid July. The project was executed by a freelancer who used to work on building PXI systems (a similar hardware system for this project) that saved output data in TDMS format. The final code set has been delivered and is currently under modification to be merged into the ParkSEIS-HMA software package. It is not an entirely independent C++ code set, but has a dependency on the NI's built-in library that needs to be downloaded online and installed on the computer that runs the ParkSEIS-HMA package.

September, 2020

- **Project Updates at 2020 NRRA Pavement Workshop (Task #1)**

The monthly meeting was organized via Skype and the minutes were posted on the web page 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 each month to reflect progress.

- **Project Updates at 2020 NRRA Pavement Workshop (Task #1)**

Project updates have been presented as part of a 2020 NRRA workshop series on Thursday, September 3, 2020. The initial development, progress made so far, and the future direction of the project development have been presented during a 1-hour workshop. The overall summary of the project and the software development were presented by the principal investigator, Dr. Choon Park, while the hardware development was presented by co-investigators, Dr. Nils Ryden and Dr. Josefin Starkhammar. A total of 45-min presentations were followed by a 15-min Q&A session. NRRA posted the entire presentation on YouTube.

- **Automatic Muting (AUTO Mute) Refinement – Data Acquired on September 1 (Task #2 & #3)**

New field operations were conducted on September 1, 2020, at the same place used previously for data sets collected during July and August. Among many 48-channel records collected (about 500 of them), two TDMS files were obtained from the Team Sweden; i.e., “2020-09-01_19_12.TDMS” and “2020-09-01_19_24.TDMS” files that contained 100 and 50 field records, respectively. The same pre-trigger time of 0.5-ms was used. This 0.5-ms time, firstly used in August, turned out later (late August) too short to capture the earlier-arrival Lamb waves for the records obtained from the reverse shots (i.e., from the impact by the source attached on the back-side of the receiver array off the 48th channel) because of the longer distance between the impact point and the array. There was a total of 32 reverse-shot records for the “2020-09-01_19_12.TDMS” data set that contained a total 100 records, while all 50 records were from the forward shots for the “2020-09-01_19_24.TDMS” data set.

First, the AUTO Mute algorithm previously developed and tested on a limited amount of field records (e.g., data sets from July and August) has been tested on these two data sets to evaluate the accuracy in the muting windows for air-wave and pre-Lamb waves. Results for all 150 records showed the AUTO Mute was highly effective when the raw records and the muted records were visually compared side-by-side. These comparisons of seismic records are presented in this report. Second, data qualities are examined in dispersion images to evaluate the effective recording of Lamb waves. While all reverse-shot records did not have any Lamb waves in the target frequency bands that are needed for the velocity (Vs) and thickness (H) evaluations (e.g., 10 kHz – 30 kHz), 54 forward-shot records (out of 68 such records) were in good quality that can allow a reliable Vs and H evaluations for the “2020-09-01_19_12.TDMS” data set. On the other hand, 39 records (out of 50) were in good quality for the “2020-09-01_19_24.TDMS” data set. These results put the “accept” rate of 80% and 78% for the two respective data sets.

Study of the optimum configuration for the 1D array has been one of the main goals of using the old (48-channel) system to collect field data under various different conditions (e.g., different section of the road, different temperatures, different source characteristics, etc.). Based on the test results from a limited amount of field data sets (e.g., the ones from July and August), it has been tentatively assumed that the 16-channel array with 3 times receiver spacing (i.e., 3dx) would be the most optimum configuration. With relatively vast amount of field records now available (i.e., 150), the test has been repeated to reinsure this 3-dx-16-channel assumption. This time, the AUTO Mute was applied to both full 48-channel records and the resampled 3dx-16-channel records to examine if there is any reduction in the effectiveness due to the reduced number of channels. The AUTO Mute results of 48-channel and 3dx-16-channel records are presented side-by-side in this report for visual comparison.

Then, dispersion images for the 3dx-16-channel records were obtained and compared side-by-side with those from the full (48) channel records by displaying them for the “2020-09-01_19_12.TDMS” data set in this report. No noticeable visual differences were observed from both the raw-seismic-data and the dispersion-image comparisons for the target frequency band (e.g., 10 kHz – 30 kHz). However, more systematic comparisons will be made in the near future by comparing key analysis results (e.g., Vs and H) from both data sets.

- **TDMS Data Format (Task #3)**

The C++ codes written by a freelancer have been refined so that they can be incorporated into the ParkSEIS-HMA software module without any clash. It seems the codes were written in C codes (instead of C++) because the NI library components support only C codes. Some parts of the codes were restructured so that they contain only C components without foreign C++ components (e.g., classes). It seems that they are properly working, at least, with all TDMS files collected so far. The new round of testing will be executed when the TDMS file of finalized structure is collected by using the new system for 1D array (sometime in November).

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 the first 3 tasks (#1 – #3) by using the quantified indices used in the progress report form (Exhibit E in the project contract) submitted each month. These values are presented in tables and then graphically displayed by using charts in the next two pages, respectively.

Work Completed – Prime* Contractor

This Period (%)

Task	Previous Quarter (Q2-2020)			This Quarter (Q3-020)		
	April	May	June	July	August	September
#1	21.2	4.2	2.3	**7.7**	**6.2**	**5.4**
#2	0	0	0	**0**	**0**	**0**
#3	4.4	11.9	6.3	**3.8**	**3.1**	**3.4**

To Date (%)

Task	Previous Quarter (Q2-2020)			This Quarter (Q3-020)		
	April	May	June	July	August	September
#1	45.3	49.6	51.9	**59.6**	**65.8**	**71.2**
#2	0	0	0	**0**	**0**	**0**
#3	18.9	30.8	37	**40.8**	**43.9**	**47.3**

Work Completed - Sub** Contractor

This Period (%)

Task	Previous Quarter (Q2-2020)			This Quarter (Q3-020)		
	April	May	June	July	August	September
#1	10	2.5	2.5	**12.5**	**10.0**	**5.0**
#2	1	2.4	5.8	**3.8**	**2.2**	**8.1**
#3	6.7	13.3	0	**13.3**	**0**	**0**

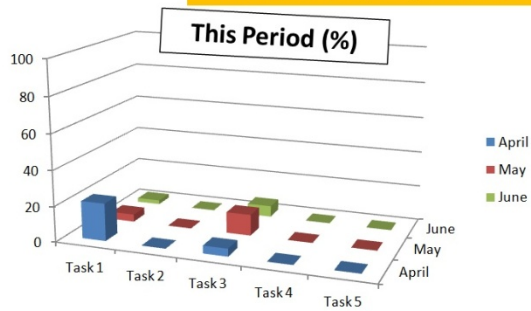
To Date (%)

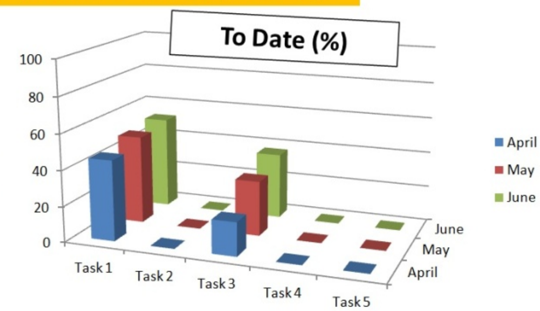
Task	Previous Quarter (Q2-2020)			This Quarter (Q3-020)		
	April	May	June	July	August	September
#1	50	52.5	55	**67.5**	**77.5**	**82.5**
#2	3.8	6.2	12	**15.8**	**18.0**	**26.1**
#3	6.7	20	20	**33.3**	**33.3**	**33.3**

*Park Seismic LLC, **Norrfee Tech, AB

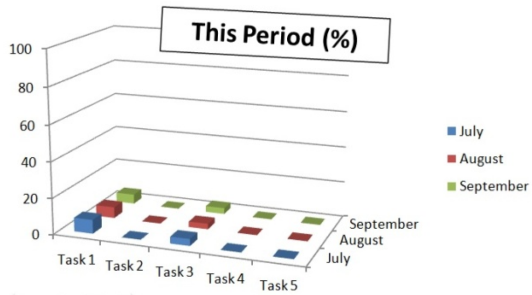
Prime Contractor (Park Seismic LLC)

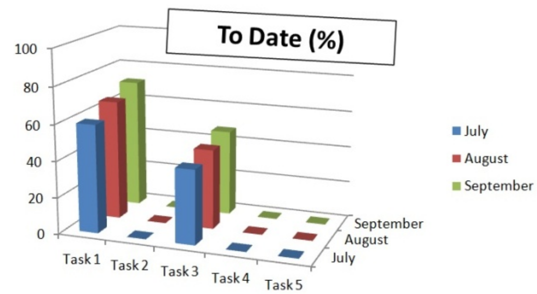
Previous (2nd) Quarter (March – June, 2020)





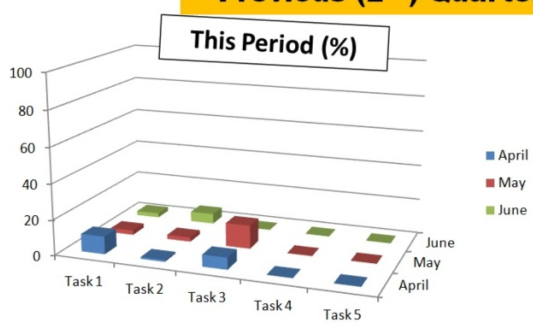
This (3rd) Quarter (July – September, 2020)

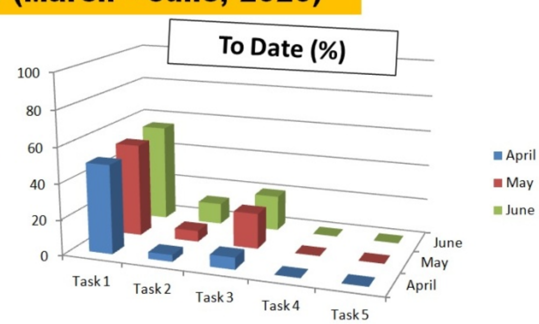




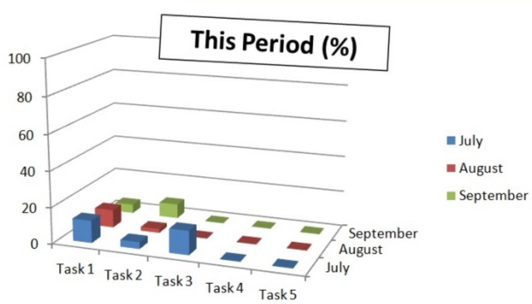
Sub Contractor (Norrfee Tech, AB)

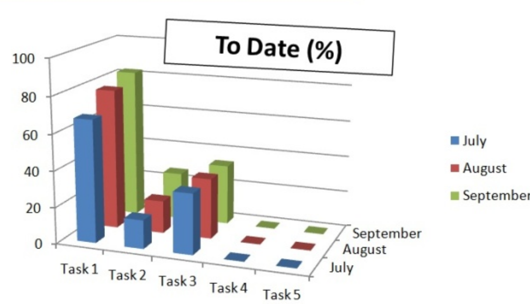
Previous (2nd) Quarter (March – June, 2020)





This (3rd) Quarter (July – September, 2020)





PROJECT PROJECTION

Projections made in the three tasks (#1 – #3) for the next three months (Q4-2020) are summarized below.

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

  The first Joint Field Test (JFT) will take place during next quarter (Q4) (October - December) in a "remotely-joint" manner. Once the test week is set, both software developer (Park Seismic) and hardware developer (Norrfee Tech) will participate in the test in an alternating manner for a 1-week period. For example, Norrfee Tech may go out to collect field data with specific objects on one day and send the collected data to Park Seismic overnight. Then, the Park Seismic conducts its own analysis of the data set using the software (ParkSEIS-HMA) for specific purposes related to the software calibration. On the next day, both parties can have a conference to talk about possible issues and subsequent improvements. This can be repeated if necessary.

  It seems this 1st JFT will take place either sometime in November or early December. Detailed format of the JFT will be discussed during the monthly meeting on Tuesday, October 27, 2020. The date of JFT can be determined before then.

  Progress for all three tasks will be continuously summarized each month and posted on the web. The monthly meeting will continue and the minutes will be available online.

- **Task #2: Building 1D System for the 1st Joint Field Test (JFT)**

  Configuration for the 1D system (e.g., receiver spacing, number of channels, amplification, etc.) will be finalized during early October and the system building process will start immediately after so that the system can be available before the JFT in November or early December. It seems highly likely that the system will consist of 16 channels with three times the current MEM microphone spacing (3dx) between channels. The new system will have its own amplifier to fully utilize the increased dynamic range (16 bit) of ADC.

  A new field laptop computer with windows operating system (USA version) will be procured and used during the 1st JFT.

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

  A method of detecting new seismic data files appearing on the PXI system will be developed. This will convert original raw data files in TDMS format (*.tdms) into ParkSEIS (PS) format (*.dat) in a real-time mode.

  The automatic mute algorithm (AUTO Mute) will be continuously refined by using more diverse field data sets. This algorithm will be jointly tested with a separate module that evaluates the overall quality (e.g., SN ratio) of an obtained field record for QA/QC purposes. The signal-enhancing process (SEP) will also be added in the pre-conditioning process that includes the AUTO Mute and QA/QC modules.

The production module for velocity (Vs) and thickness (H) evaluation will be completed for the 1D system. It will automatically build up a 2D cross section in a pseudo-real-time mode as more field records are being acquired while the system is rolling. The module will be tested on the compatibility with the hardware acquisition software through the remote desktop control and the network-drive approaches. The parallel process will be considered for the production module to reduce the overall computing time, which is critical for the in-field analysis package.