Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287

Report – 1st Quarter, 2021

Prepared By

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Submitted To

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SUMMARY

We provide a progress report for the 1st quarter of 2021. 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, except for the month of March 2021. As of March 31, the Park Seismic LLC website has been put on hold for any changes during the next 1-2 months while the site is undergoing a renovation.

Progress summary of the previous quarter (Q4-2020) 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 that has been posted online. 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 (Q2-2021) are prepared by compiling feedback and plans from all project participants.

MONTHLY PROGRESS

January 2021

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

The 4th quarterly report (Q4-2020) 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 Test with New 16-Channel Array and DAQ at Gunpowder Mill (January 9, 2021) (Task #2)**

Norrfee Tech tested the newly built 16-channel array in the field (see the photo on the web). The array is now attached through more rigid metal bar (instead of wood bar) to the main frame of the bicycle rack. The array was wrapped with cloths to protect it from external wet conditions on the road. The impact source was attached to an independent bar separate from the receiver array to minimize the possible transmission of its impact vibration to the receiver array. It was tightened to the bar through a rubber cushion to further insulate its vibration from the holding bar. This time, the impact source ("bouncing ball") was attached to the bar through a strap shorter than previously used. This resulted in more frequent impacts. More details about the new array, its

attachment on the bicycle rack, waveforms collected at two different speeds (slow 15 km/h and fast 30 km/h), voltage ranges of waveforms, 16-channel field records, and their corresponding dispersion images are presented in this report prepared by Norrfee Tech.

- **AUTO Evaluation of Data from Gunpowder Mill by Using ParkSEIS-HMA (Task #3)**

The ParkSEIS-HMA used two of the field data sets obtained during the field campaign outlined above to test the automatic analysis mode of the software. One data set ("T210109_25.TDMS") contained ten (10) records of all correctly triggered acquisition. The other data set ("T210109_140.TDMS") contained one hundred (100) records of both false and valid triggers.

The results of shear-wave velocity (Vs) and thickness (H) profiles are presented in this report for different "lateral continuity (LC)" values that are directly related to the lateral averaging of the dispersion images. The report also presents evaluation results for different attributes such as DC bias, raw field records, automatic muting, and dispersion images for different LC values for all constituent records (10 and 100) of the two data files.

February 2021

✓ **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.

- **The First Joint Field Test (1st JFT) on February 23, 2021 (Task #2 & #3)**

The 16-channel acquisition system built in January has been used for the first Joint Field Test (JFT) along with the ParkSEIS-HMA software package on February 23, 2021. The test lasted about 2 minutes driving the survey vehicle about 1 km distance. It collected 50 TDMS files that contained fifty (50) 16-channel records per file, totaling 2500 records (measurements). This corresponds to one measurement about every 0.4-m distance. The photo on the web shows the runtime operation of the ParkSEIS-HMA software inside the vehicle during the field data acquisition.

- **Evaluation of Data From the 1st JFT with ParkSEIS-HMA (Task #3)**

The ParkSEIS-HMA software processed 200 records (out of 2500 total) during about 5-minute duration on a laptop computer inside the survey vehicle. It had to be stopped while it was processing more records because of the concern that the acquisition system (PXI unit) might be consuming too much power. Nonetheless, the program displayed results of the shear-wave velocity (Vs) and thickness of the HMA pavement as shown on the web for the number of records it processed before its termination.

Further evaluation of all acquired records and also the ParkSEIS-HMA software that encountered a few error messages during the test is currently under investigation. In addition, possible ways to reduce the overall process time are continuously under scrutiny. Currently, it takes about one (1) minute to process one hundred (100) 16-channel records.

March 2021

Because of the inability to update the website as of March 31, the monthly progress page has not been updated for this month. Instead, the related contents otherwise available online are provided in appendices attached at the end of this report.

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

The monthly meeting was organized via Skype and the minutes are presented in Appendix I. Monthly invoicing and payment to the sub-contractor has been managed by the staff.

- **The First Joint Field Test (1st JFT) on February 23, 2021 - The Results (Task #3)**

Norrfee Tech performed the first joint field test (1st JFT) on February 23, 2021, on a road near Lund, Sweden. The purpose was to jointly test the hardware system of the 16-channel MEMS microphone array and the ParkSEIS-HMA software under a real survey condition. The survey vehicle moved at about 15 knot/hour (~17 MPH) speed for about 4 minutes to travel about 1.3 km distance. This collected fifty (50) TDMS files (T210223_1.TDMS – T210223_50.TDMS) of fifty (50) 16-channel records per TDMS file except for the last TDMS file of only one (1) record/TDMS. The 48th file ("T210223_48.TDMS") was a faulty file with incorrect channel assignment, cause of which is under investigation. In consequence, a total of 2401 records were collected.

Number of records and survey distance outlined above indicate that, on average, one impact was delivered every 0.5-m distance. The ParkSEIS-HMA software was performing file transfer, conversion, and subsequent data analysis in pseudo-real-time mode inside the survey vehicle. However, the software had to be terminated prematurely after processing six (6) TDMS files. This was because the acquisition (PXI) system had to be powered down as it was consuming a significant power of the electric vehicle. The ParkSEIS-HMA, therefore, is currently under modification so that it can separate its file transfer & conversion from the analysis part of the software. This will enable the PXI system to be powered down as soon as the survey finishes and the ParkSEIS software can continue the analysis on the installed laptop computer.

After the field operation, the ParkSEIS-HMA processed all (50) TDMS files through a simulation of the JFT in the lab by feeding each TDMS file manually from a network drive (that represented the PXI system). The process results showed acquired Lamb waves have extremely high signal-to-noise (SN) ratio of about 93%; e.g., a SN of 100% means all Lamb waves and no noise, while 0% means all noise and no Lamb waves. This unusual quality seems to be the result of the high fidelity of the new acquisition system. It seems the low-temperature of the asphalt also contributed to the high quality because of the low attenuation of the seismic waves. There were eight (8) false-trigger (FT) records out of 2350 total production records, which puts the FT ratio under 0.4%. The results of shear-wave velocity (Vs) showed an average of about 1800 m/s, while those of the thickness (H) showed an average of about 10 cm. Both values seem highly reasonable although the true values are still unknown. The temperature data showed an average of 6.5 degrees in Celsius.

The report presented in Appendix II has more details about the results and future plan for the 2D system.

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 on this page and then graphically displayed by using charts in the next page.

Work Completed – Prime* Contractor

This Period (%)

Task	Previous Quarter (Q4-2020)			This Quarter (Q1-021)		
	October	November	December	January	February	March
#1	4.2	3.8	5.8	4.6	3.8	2.3
#2	0	0	0	0	0	0
#3	5.3	5.3	2.8	3.8	2.3	3.8

To Date (%)

Task	Previous Quarter (Q4-2020)			This Quarter (Q1-021)		
	October	November	December	January	February	March
#1	75.4	79.2	85	89.6	93.5	95.8
#2	0	0	0	0	0	0
#3	52.7	58	60.8	64.5	66.9	70.6

Work Completed - Sub** Contractor

This Period (%)

Task	Previous Quarter (Q4-2020)			This Quarter (Q1-021)		
	October	November	December	January	February	March
#1	2.5	2.5	2.5	2.5	2.5	2.5
#2	8.1	10.1	13.5	12.4	6.5	1.9
#3	0	20	0	0	0	0

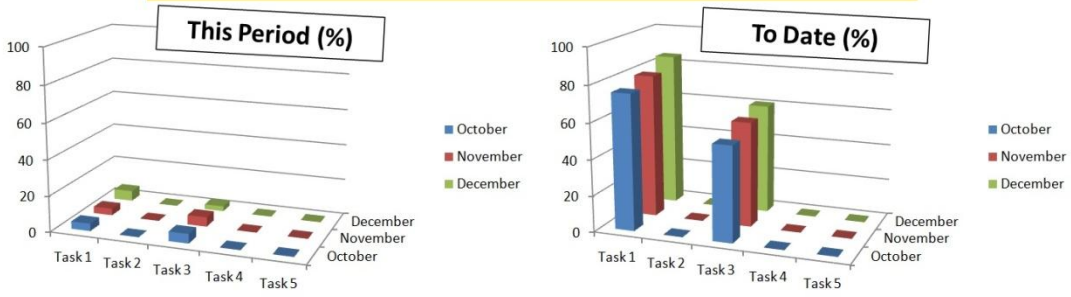
To Date (%)

Task	Previous Quarter (Q4-2020)			This Quarter (Q1-021)		
	October	November	December	January	February	March
#1	85	87.5	90	92.5	95.0	97.5
#2	34.1	44.2	57.7	70.1	76.5	78.4
#3	33.3	53.3	53.3	53.3	53.3	53.3

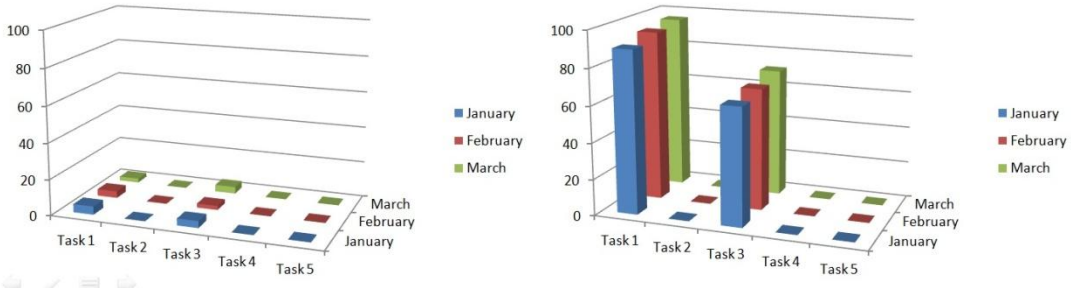
*Park Seismic LLC, **Norrfee Tech, AB

Prime Contractor (Park Seismic LLC)

Previous (4th) Quarter (October – December, 2020)

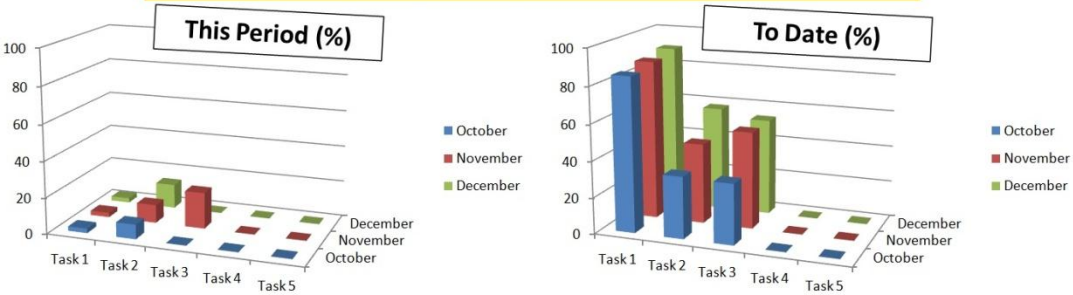


This (1st) Quarter (January – March, 2021)

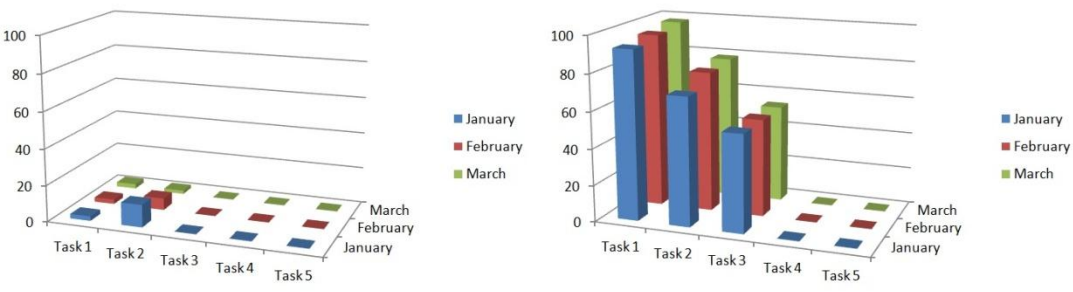


Sub Contractor (Norrfee Tech, AB)

Previous (4th) Quarter (October – December, 2020)



This (1st) Quarter (January – March, 2021)



PROJECT PROJECTION

Projections made in the three tasks (#1 – #3) for the next three months (Q2-2021) are summarized below.

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

  The contract will be amended in two aspects; (1) change in project end date from current October 31, 2021, to June 30, 2022, and (2) change in project budget allocation without change in the total amount already granted. The change in the project period is necessary because of two reasons. Firstly, it would be more practical to make the final delivery and demonstration occur at the NRRA-2022 conference scheduled in June 2022. Secondly, it is necessary to allow more field testing time to complete the ParkSEIS-HMA software package after the hardware system completion, which is currently scheduled sometime later part of this year (e.g., October 2021). Due to the COVID uncertainties for the last year, there have been significant delays and changes in the overall execution plan that resulted in modifications in the project period, budget allocation, and execution details for the remaining period. The new execution plan will include a schedule for Norrfee Tech to deliver the completed hardware system to Park Seismic by the end of October 2021. Park Seismic will use it for the completion of the software package through in-house testing. Details about the new execution schedule and the new budget plan will be discussed among investigators during the earlier part of the next quarter. The request of contract amendment will be prepared to submit it in June.

- **Task #2: Completion of 1D Hardware System and Moving Onto 2D Hardware System**

  The first joint field test (JFT) executed in February demonstrated the superb quality of the surface waves recorded with the newly built 1D system consisting of AD device and source-receiver-array configurations. In this sense, the most critical aspect of the hardware system has been tested highly favorably. Several minor issues, however, remain to be addressed in the following categories:

  - ✓ The system generated one TDMS file of incorrect format during the JFT out of fifty (50) files recorded. The cause has to be investigated to prevent it from happening again.
  - ✓ Update of GPS data occurs somewhat randomly instead of planned every one second. Besides, a few different values (e.g., 2-3) are saved simultaneously when an update occurs. Considering the GPS information is the only tool to assess the spatial sampling density of the road, its reliability has to be improved.
  - ✓ It is not clear at this moment how the optimum triggering voltage is determined. It seems that the sound level of the impact source is the key element. It may also have to be adjusted depending on the distance (X1) between the impact point and the trigger microphone. It seems a clear guideline to set an optimum level will have to be established in the future. Or, the acquisition control software will have to adjust it automatically (if possible) based on the key information such as X1, type of impact source, etc. The trigger level control should also be available from the ParkSEIS-HMA in the future.
  - ✓ It seems the measurement voltage level, which currently is set to 1 volt, can be reduced, for example, to 0.5 volt. This may result in recording of clipped air waves. However, the

full dynamic range can be better utilized to amplify the signal Lamb waves with a higher resolution. This control should also be available from the ParkSEIS-HMA in the future.

- ✓ More joint field tests (JFT's) with ParkSEIS-HMA will be necessary shortly to address issues and topics mentioned above, and also issues and features of ParkSEIS-HMA outlined below in Task #3.

Design and build of the 2D system will start at the earliest part of the next quarter (e.g., April). It seems that the Lamb-wave attenuation inside the asphalt pavement has been underestimated previously. In consequence, it was previously assumed the separation (dY) between consecutive 1D receiver arrays could be as wide as 1-2 ft, and the common source could be placed as far as 2-4 ft ahead of the arrays (i.e., X1=2-4 ft). However, data collected so far indicates the maximum distance of the source (X1) can only be anywhere between 15 cm and 20 cm. This limits the maximum dY to be about 1-ft when all four (4) arrays are radially arranged along a half circle. Then, the maximum transverse width of pavement that the final 2D system can measure simultaneously will be limited to 3-4 ft. A few field tests are necessary to evaluate how much X1 can be extended by modifying current configurations in recording device and also in the impact source.

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

From the 1st JFT, the ParkSEIS-HMA demonstrated it can evaluate the velocity (Vs) and thickness (H) of asphalt pavement in a fairly reliable and also presumably accurate manner. In this sense, the most critical aspect of the software package has been tested highly favorably. It, however, generated two error messages during the JFT while processing the recorded data in a pseudo-real-time mode. The exact cause was not found yet. The program was modified afterward based on a few speculated causes and therefore, it has to be tested through another field operation soon.

Several developments will be completed for the 1D system in the following categories:

- ✓ Graphical User Interface (GUI) will be completed to pass the acquisition-related parameters to the PXI control software, such as trigger and measurement voltage levels, number of records per TDMS file, pre-trigger time, number of samples, sampling frequency, etc.
- ✓ Output results (Vs and H) are currently displayed for record (i.e., measurement) numbers. An option will be available to display them in survey distance (m). This should be available once the GPS display mentioned below is available.
- ✓ GPS data will be displayed in a separate chart in the distance (m) for Easting (X) and Northing (Y) (i.e., UTM coordinates).

Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287

APPENDIX I: Monthly Meeting Minutes (March 2021)

Monthly Meeting (March 2021)

Date: March 30, 2021
Time: 2:30 pm - 3:41 pm
Location: Park Seismic Office
Attendees:
In the office: Choon Park and Jin Park
Via Skype: Josefin Starkhammar, and Nils Ryden

1. **Contract Amendment Plan** (Jin proposes most, and others responded occasionally)
    a. Contract amendment needs to be prepared by August. Thus, we will have to prepare the amended proposal soon in both contract and budget, probably before May or June at the latest to account for possible further adjustment with MnDOT.
    b. The project period will be extended to June 2022 from current October 2021 to meet the final demonstration during the NRRA conference in 2022.
    c. Choon proposed that the final hardware system be delivered to Park Seismic by October 2021 so that it can be used for more effective development of the ParkSEIS-HMA software package.
    d. Budget hours need to be re-adjusted between Josefin and Nils because Nils will need more hours to finish the design and completion of the 2D source-receiver system. The new budget-hour plan should be available within the next month.
    e. Budget reallocation will be made and discussed during the next month's meeting with a draft plan.

2. **The First Joint Field Test (1st JFT)** (Choon proposes most, and others responded occasionally)
    a. Choon went through the data set collected during February 2021 for the 1st JFT by using a prepared power point file and commented the data quality was superb. He also discussed, asked questions, and commented on the raw TDMS files in terms of how they were collected and saved.
    b. Choon commented on the results of velocity, thickness, and temperature of the asphalt pavement. He asked questions about the temperature, timestamp, and GPS data.
    c. He mentioned the number of false trigger records, which turned out less than 0.4% for the total records acquired (about 2400).
    d. He mentioned one TDMS file had incorrect file format that caused the ParkSEIS-HMA software to clash. Josefin would check on it to figure out what caused it.
    e. Choon revisited the overall mode of operation with the PXI control software and the ParkSEIS-HMA software. He emphasized that the main software will be ParkSEIS-HMA that controls both data acquisition and process of the entire system. The PXI control software will be accessed only when special circumstances occur that need to check and adjust parameters for data recording that are not controlled by the ParkSEIS-HMA.
    f. Choon wanted to have a separate technical meeting with Nils in one week to discuss the overall design of the 2D system.

Agreed:

- Park Seismic and Norrfee Tech will perform another joint field test within the next month.
- Norrfee Tech and Park Seismic will prepare its own amended contract and budget plans before the next month meeting.

Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287

APPENDIX II: Report ("First Joint Field Test - Results")

The First Joint Field Test (1st JFT)
- Results -

Choon Park, Ph.D.

Principal Geophysicist
Park Seismic LLC

Seismic Approach to Quality Management of HMA

MnDOT Contract No. 1034287
Federal Project Number: TPF-5 (341)
Execution: January, 2020 - December, 2021

Principal Investigator: ***Choon Park****, Park Seismic LLC, Shelton, Connecticut, USA*
Co-Investigators*:* ***Nils Ryden*** *and* ***Josefin Starkhammar****, Norfee Tech, Lund, Sweden*
Administrative Staff*:* ***Jin Park****, Park Seismic LLC, Shelton, Connecticut, USA*

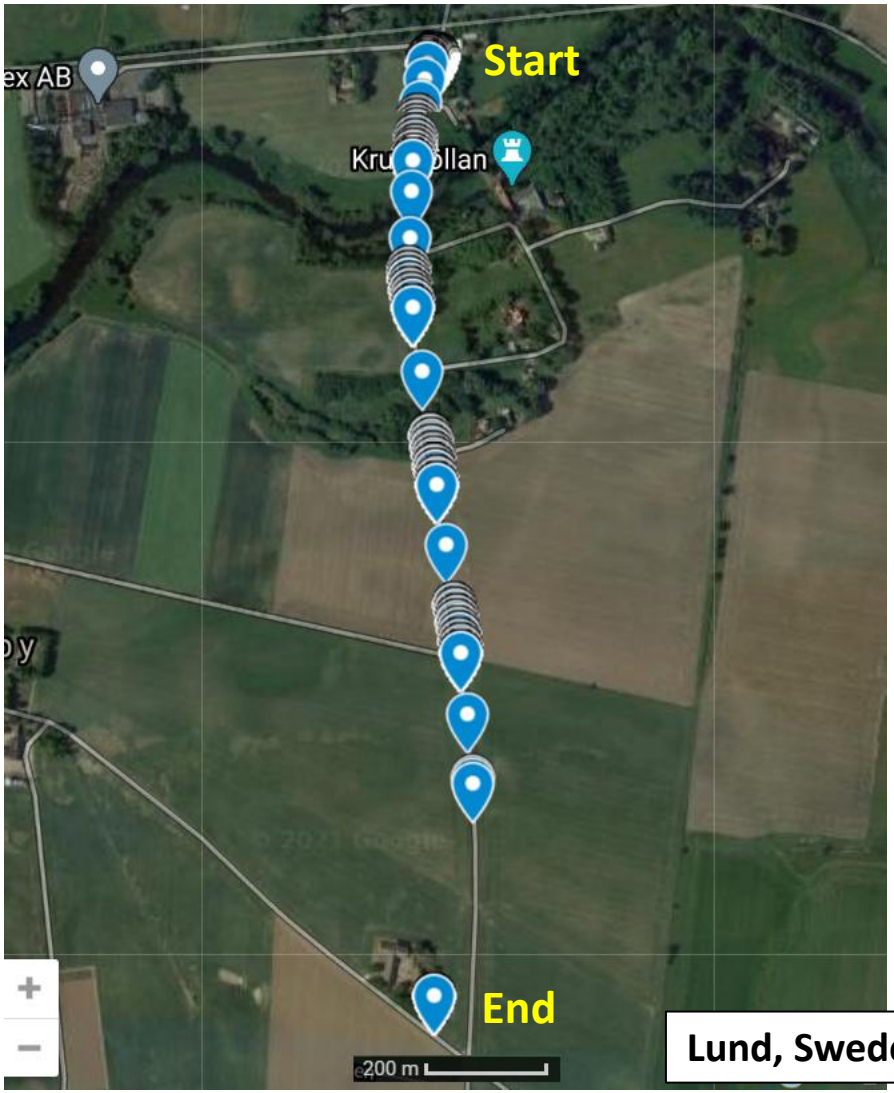
SUMMARY

- Norrfee Tech performed the first joint field test (1st JFT) on February 23, 2021, on a road near Lund, Sweden. The purpose was to jointly test the hardware system of the 16-channel MEMS microphone array and the ParkSEIS-HMA software under a real survey condition.
- The survey vehicle moved at about 15 knot/hour (~17 MPH) speed for about 4 minutes to travel about 1.3 km distance.
- This collected fifty (50) TDMS files (T210223_1.TDMS – T210223_50.TDMS) of fifty (50) 16-channel records per TDMS file except for the last TDMS file of only one (1) record/TDMS. The 48th file ("T210223_48.TDMS") was a faulty file with incorrect channel assignment, cause of which is under investigation. In consequence, a total of 2401 records were collected.
- Number of records and survey distance outlined above indicate that, on average, one impact was delivered every 0.5-m distance.
- The ParkSEIS-HMA software was performing file transfer, conversion, and subsequent data analysis in pseudo-real-time mode inside the survey vehicle. However, the software had to be terminated prematurely after processing six (6) TDMS files. This was because the acquisition (PXI) system had to be powered down. It was consuming a significant power of the electric vehicle. The ParkSEIS-HMA, therefore, is currently under modification so that it can separate its file transfer and conversion part from the analysis. This will enable the PXI system can be powered down as soon as the survey finishes and the software can continue the analysis on the installed laptop computer.
- After the field operation, the ParkSEIS-HMA processed all (50) TDMS files through a simulation of the JFT in the lab by feeding each TDMS file manually from a network drive (that represented the PXI system).

SUMMARY (Cont'd)

- The process results showed acquired Lamb waves have extremely high signal-to-noise ratio of about 93%; e.g., 100% means all Lamb waves and no noise, while 0% means all noise and no Lamb waves). This unusual quality seems to be the result of the high fidelity of the new acquisition system. It seems the low-temperature of the asphalt also contributed to the high quality because of the low attenuation of the seismic waves.
- There were eight (8) false-trigger (FT) records out of 2350 production records, which puts the FT ratio under 0.4%.
- The results of shear-wave velocity (Vs) showed an average of about 1800 m/s, while those of the thickness (H) showed an average of about 10 cm. Both values are believed highly reasonable.
- The temperature data showed an average of 6.5 degrees in Celsius.
- Survey area , acquired data sets, and analyzed results are presented in this report.
- Graphical discussions of the near-future 2D array system have been presented also.
- Possible change of dynamic range in AD conversion that can further increase the Lamb wave quality is presented in the last two pages.

The 1st Joint Field Test (1st JFT) (Lund, Sweden, Feb 23, 2021)

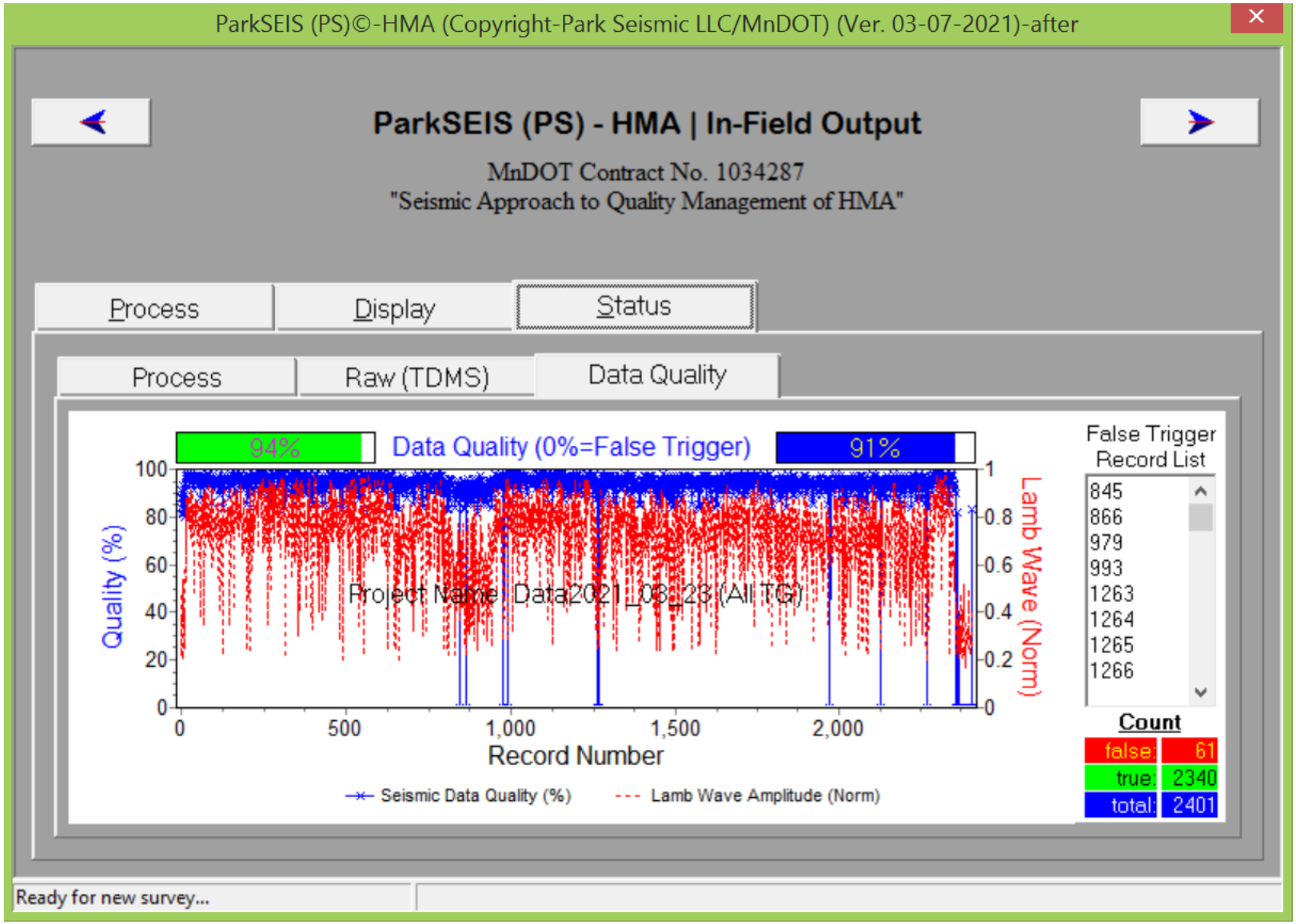


Lund, Sweden

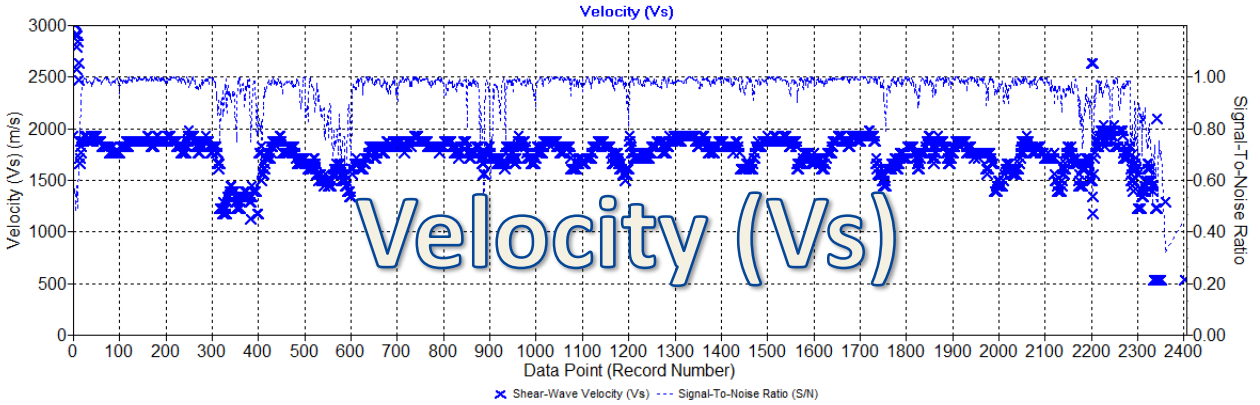
- For a distance about 1 km long at a cruising survey speed of about 15 knots/hour (17 MPH)
- About 4 minutes of survey driving
- Although GPS was designed to be updated every 1 second, it was updated rather randomly during the survey. The cause is under investigation.
- Data points at about every 0.5 m
- A total of about 2400 data points
- Fifty (50) TDMS files with fifty (50) 16-channel records/TDMS file

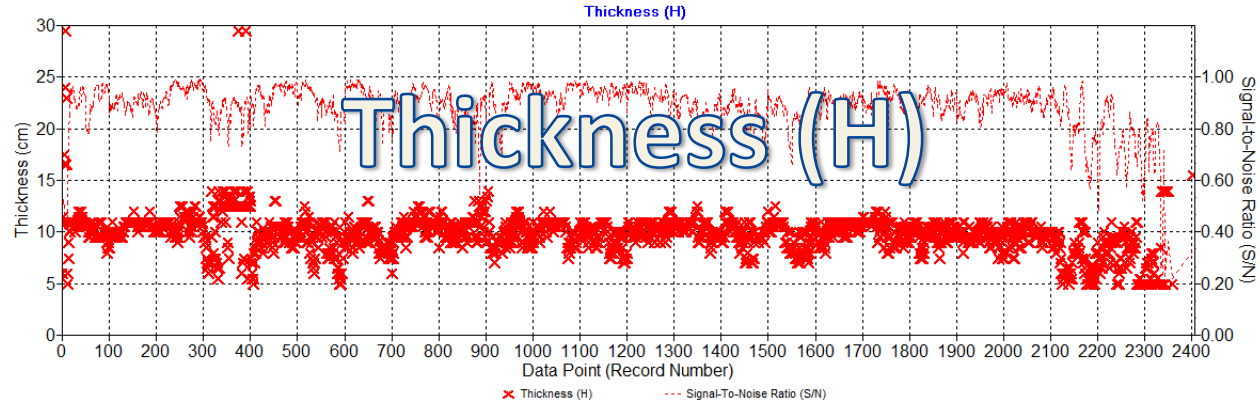
QA/QC on ParkSEIS-HMA

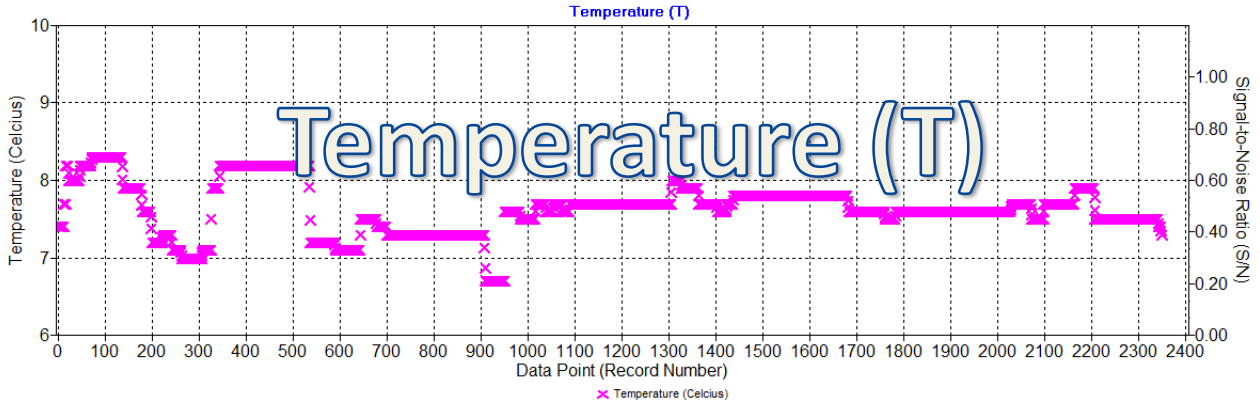
- Excellent quality (S/N ≈ 94%, ~0.3% false trigger)



1st JFT Data (Feb 23, 2021) – Results







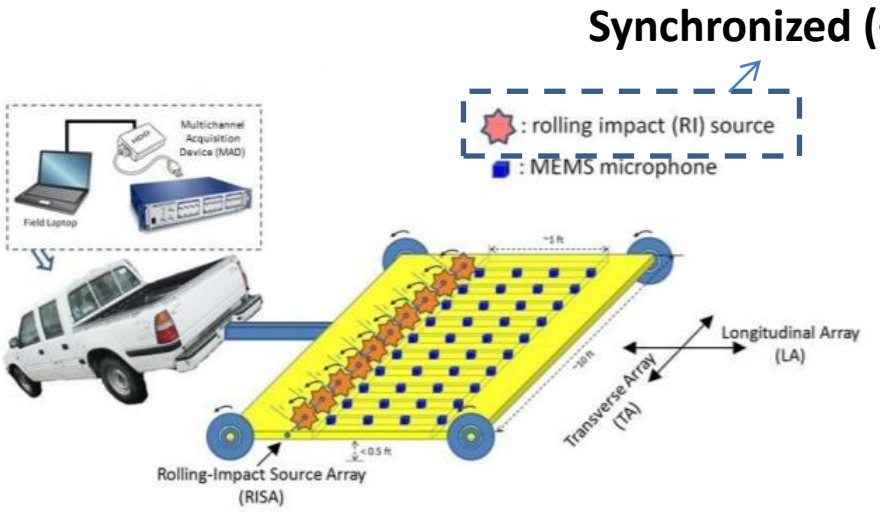
Software and Survey – Revisit

- Main Software – ParkSEIS HMA
  - Key ACQ control parameters in a dedicated GUI: ARM/DISARM/STOP, trigger level, recording time, pre-trigger time (e.g., continuous control with a track bar), etc.
  - Analysis: In-Field and In-Office modes

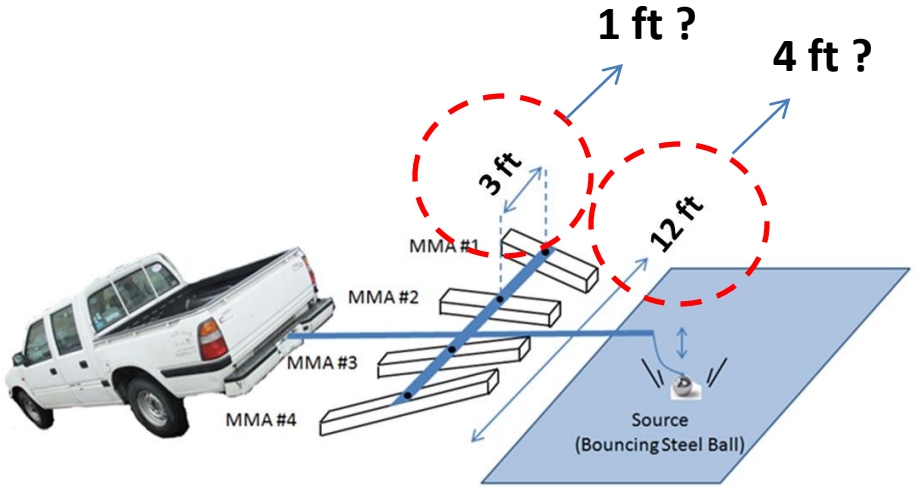
- PXI System
  - Control software as startup program (i.e., automatic execution when PXI is turned on), and self termination (i.e., automatic termination when STOP.TXT or system turned off)
  - Remote desktop access – only when necessary
- Normal mode of survey
  - Start driving along a given road segment
  - Check data points on the X-Y map
  - Drive back and forth to fill more data points
  - Check results (velocity and thickness)?

2D System – Receiver Array and Source

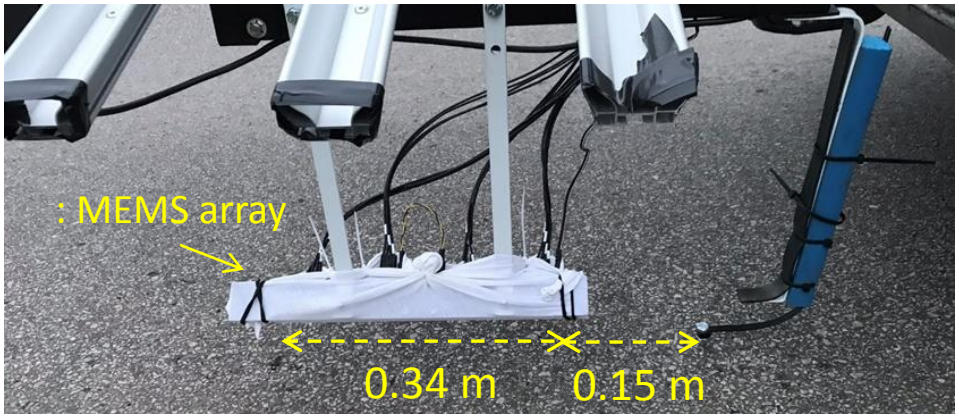
Original Proposed ("Impractical")



1st Update (Sept-2020)

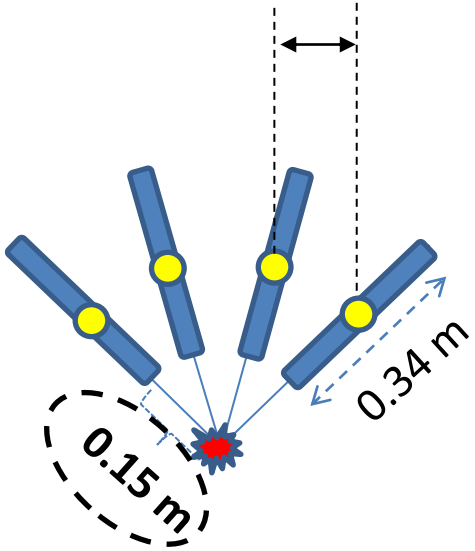


One Common Source with Radial Receiver Arrays

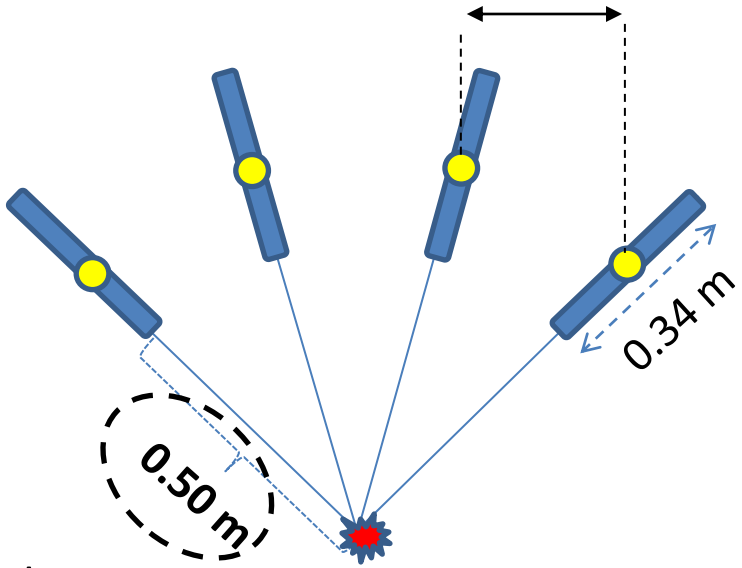


- True multichannel acquisition to cover 2D
- Synchronized recording for all (4) arrays
- Source power and the attenuation are the limiting factors.

0.14 m (Too Short!)



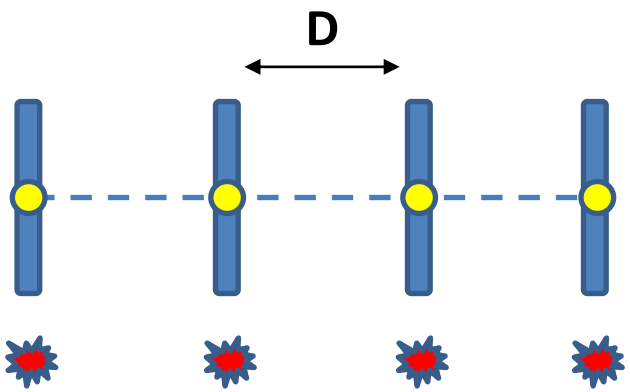
0.30 m (Min. Optimum!)



: MEMS array center

Independent Source

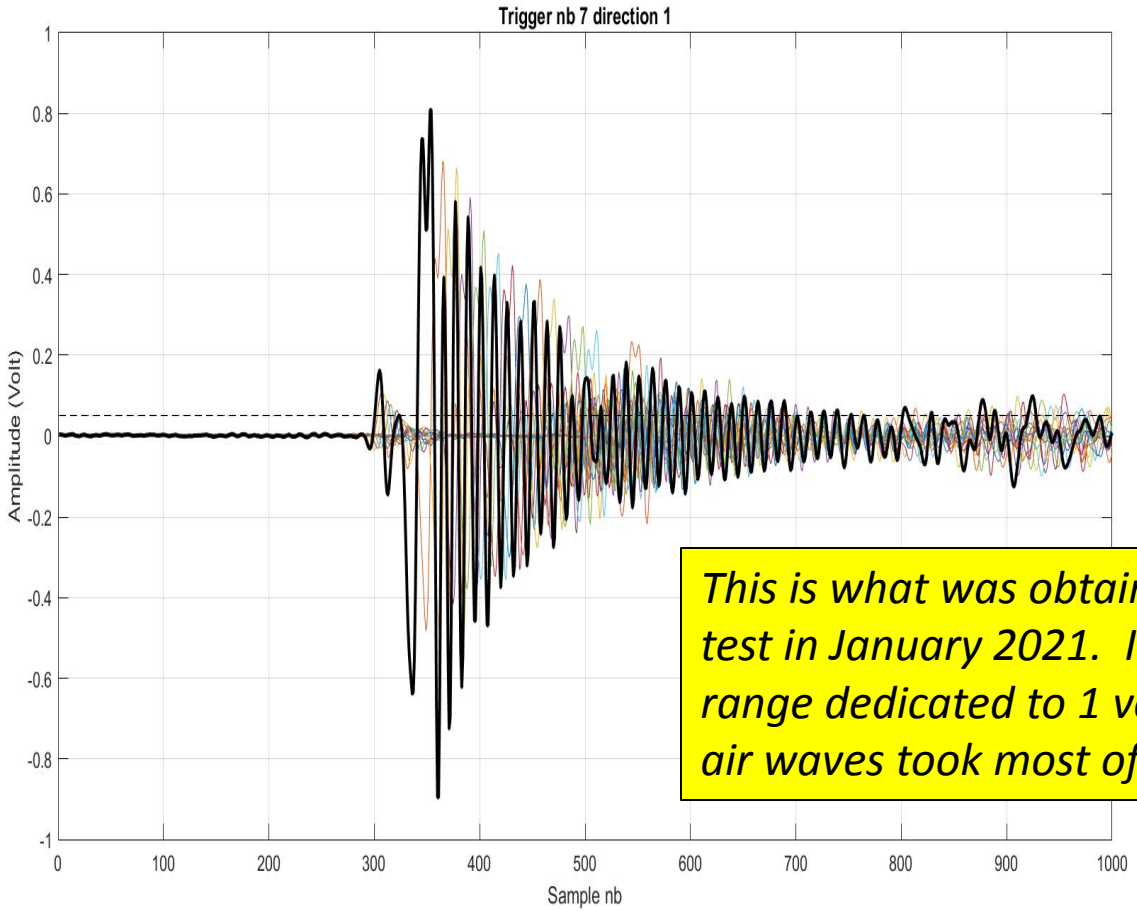
- Current source can be used.
- Separation (D) is highly flexible
- Dmin (e.g., > 0.5 m) to avoid interference from other array(s)
- Waste of channels (i.e., only 16 channels are used at a time, not 64 channels) – 16-channel ACQ.



: MEMS array center

Field test 210109, record nb 7 in tdms file T210109_25

Example data set at low speed about **15 km/h**
Similar data as before but now with about 30 times higher amplitudes (from more amplification but also colder and stiffer asphalt)
Noise level about 3 mV, peak surface wave about 0.2 V, peak direct air wave about 1.0 V



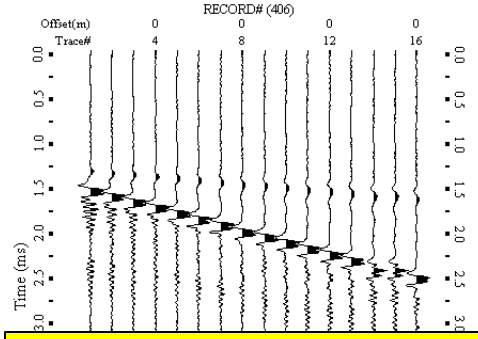
DAQ parameters and temp
RecordLength = 1000 samples (5 ms)
TriggerLevel = 0.05 Volt (300 samples pre-trigg)
DynamicRange = 1 Volt
SampleRate = 200 kHz
Temp = 1 deg C

PLEASE NOTE: TRIGGER LEVEL WILL BE INCREASED NEXT TIME!

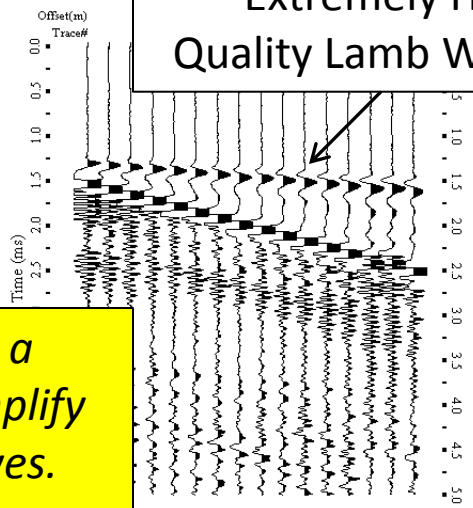
This is what was obtained during the field test in January 2021. It shows a dynamic range dedicated to 1 volt range in which the air waves took most of its range.

Normal Clipped

“T210223_9.TDMS”

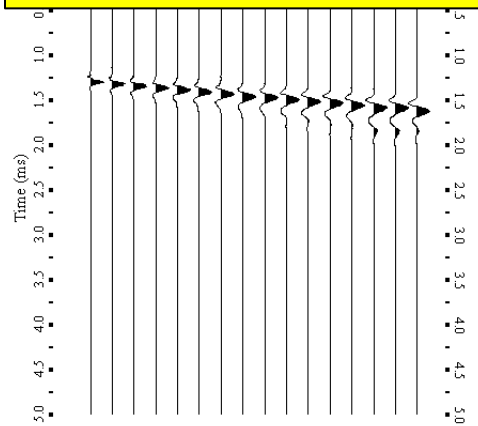


RAW



“Extremely High Quality Lamb Waves”

This shows a possible dynamic range applied to a lower volt (e.g., 0.3 volt) may still be able to amplify the Lamb waves although it will clip the air waves. The “MUTE” record displayed below shows the clipped air wave does not adversely influence the mute operation.



MUTE