

Spatial Re-sampling to Evaluate Optimum Receiver Spacing for MEMS Microphone Array – SUMMARY

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Spatial Re-sampling – SUMMARY

- A 48-channel field record with a channel spacing (dx) of 0.752 cm is tested to evaluate the optimum channel spacing (dx -opt) and, therefore, the optimum of number of channels per (longitudinal) array (N Ch-opt), while keeping the overall length of the array fairly the same (i.e., ~ 35 cm). This evaluation will also determine the optimum number of transverse arrays (N TR-opt) within the maximum number of channels available (64).
- Considering this 48-channel record as an ultimate reference for the highest quality one can obtain, the spatial re-sampling has been attempted to increase (decrease) the channel spacing (the number of total channels).
- The spatial resampling test included receiver spacing (number of total channels used) of $2dx$ (24-CH), $3dx$ (16-CH), $4dx$ (12-CH), $5dx$ (10-CH), $6dx$ (8-CH), $7dx$ (7-CH), $8dx$ (6-CH), and $12dx$ (4-CH). For each tested channel spacing, displays of re-sampled seismic record, corresponding dispersion image, and the evaluation of SN ratios are presented in the Appendices I-III.
- The original relatively small spacing (0.752 cm) was tested on how to minimize any adverse effect from air waves that have significantly lower velocity (e.g., 330 m/sec) than that of the pavement surface waves (e.g., 2000 m/sec). The low air-wave velocity results in very short wavelengths (e.g., 1-3 cm) at high frequencies (e.g., ≥ 10 KHz) that can adversely interfere, through the spatial aliasing phenomenon, with the useful Lamb-wave energy trend in the dispersion image, the ultimate data space that is used to evaluate velocity (V_s) and thickness (H) of the HMA layer. Therefore, it is critical to control this effect as much as possible during data acquisition (as well as during the post-acquisition data processing steps). In this sense, the Lamb waves are considered as signal, while the air waves are considered as noise during the test.
- The comparison mainly focused on the overall amplitudes of signal (Lamb) and noise (air) waves observed in the dispersion image constructed from the original and the re-sampled field records. This is accomplished through the frequency-summation (FRQ-Sum) method (see [Park, 2016](#) or see Figures 4 and 5 [here](#)) that sums all energy in the dispersion image along the frequency axis for a given frequency range (i.e., 0.1-50 KHz). Peak amplitudes in the summed curve is directly related to the signal-to-noise (SN) ratio of non-dispersive surface waves (e.g., flat portion of the fundamental-mode of asymmetric Lamb waves, A_0 , and air waves). On the other hand, the velocities where the peaks occur represent the phase velocities of the corresponding wave events.

Spatial Re-sampling – SUMMARY (cont'd)

- The most desirable configuration parameters of the array (i.e., dx-opt and NCh-opt) are the ones that result in the highest Lamb-wave (signal) amplitude and the lowest air (noise) wave amplitude.
- Two types of spatial re-sampling approaches are considered; i.e., simple re-sampling (decimation) and stack-re-sampling. Both approaches are graphically explained in the two slides following the summary. Basically, the former is identical to simply increasing the receiver (channel) spacing by using only those traces falling into the new receiver locations from the original record. On the other hand, the latter approach connects (in parallel) those receivers falling in-between the new extended receiver spacing. This approach has been used for long in the seismic exploration surveys as a field approach to attenuate the strong, but propagating at much lower velocity, the ground-roll surface waves (see Telford et al., 1976).
- Detailed testing results of the two approaches are presented separately in Appendices I and II. The side-by-side comparisons of the two approaches are presented in Appendix III.
- In the simple re-sampling case (see Table 1 and Charts 1 and 2), the peak amplitudes of signal (Lamb) waves slightly decreases as the receiver spacing (number of total channels used) increases (decreases) from 53.8% at 1dx to 45.5% at 12dx (Chart 1). The peak amplitudes of noise (air) waves also decreases from 48.5% at 1dx to 35.9% at 12dx (Chart 1). As a result, the signal (Lamb)-to-noise (air) ratio did not change significantly (e.g., 1.17 – 1.41) (Chart 2). This indicates the SN ratio is not significantly affected by the receiver spacing (or number of total channels used) within the tested range; i.e., 1dx (48-CH) – 12dx (4-CH). Details are presented in Appendix I.
- Phase velocities of signal (Lamb) and noise (air) waves evaluated from the peak amplitudes remained the same, within one velocity interval (40 m/sec) used during the dispersion image generation, at 2400 m/sec and 360 m/sec, respectively (Table 1). The relatively high velocity of Lamb waves resulted from the special type of asphalt pavement at the survey site, which is similar to the concrete pavement in shear-wave velocity (V_s). The higher air-wave velocity (than the normal 340 m/sec) resulted from the vertical offline offset of the receiver array hanging above (instead of being in direct contact with) the pavement surface by about 15 cm.

Spatial Re-sampling – SUMMARY (cont'd)

- According to the SN ratio and the accuracy in the velocity estimation outlined above, a 4-channel array with a 12dx channel spacing (9.024 cm) would be used without compromising the SN ratio between the Lamb and the air waves as far as this particular data set is concerned. However, this number of channels (4) would be too small to handle other challenges in data quality (e.g., other sources of noise). In this sense, the optimum number (NCh-opt) should be greater than ten (10) at the least.
- In the stack-re-sampling case (see Table 2 and Charts 3&4), however, the peak amplitudes of signal (Lamb) waves slightly increases (instead of decreases) until the spacing extended to 5dx (10 total channels) from 53.8% (1dx) to 56.6% (5dx), and then slightly decreases from 56.6% (5dx) to 47.1% (12dx) (Chart 3). On the other hand, the peak amplitudes of noise (air) waves rather rapidly decreases from 48.5% (1dx) to 22.2% (5dx), and then slightly increases from 22.2% (5dx) to 32.2% (12dx) (Chart 3). As a result, the signal (Lamb)-to-noise (air) ratio increases rapidly from 1.11 (1dx) to 2.55 (5dx) and then decreases from 2.55 (5dx) to 1.46 (12dx) (Chart 4). However, the SN ratio is always higher for a given re-sampled spacing (e.g., 2dx, 3dx, etc.) than that of the simple re-sampling case previously outlined (Table 2). This indicates the approach of stacking wavefields from adjacent MEMS microphone receivers enhances the relative energy of the signal (Lamb) waves while suppressing the noise (air) wave energy at the same time. This effect appears to continuously increase until the stacking takes place up to 5 consecutive receivers and then the effectiveness decreases (Chart 4).
- Phase velocities of signal (Lamb) and noise (air) waves evaluated from the peak amplitudes remained the same, within one velocity interval (40 m/sec) used during the dispersion image generation, at 2400 m/sec and 360 m/sec, respectively (Table 2).
- Again, according to the SN ratio and the accuracy in the velocity estimation outlined in Table 2, a 4-channel array with a 12dx channel spacing (9.024 cm) would be used without compromising the SN ratio between the Lamb and the air waves as far as this particular data set is concerned.

Spatial Re-sampling – SUMMARY (cont'd)

- From the experimental results outlined above for the two approaches of spatial re-sampling, it is obvious that the stack-re-sampling is superior to the other simple re-sampling approach because it increases not only the S/N (Lamb/air) but also the absolute amplitude of the Lamb waves until the spacing extends to $5dx$ (Table 2, Charts 3 and 4). This means that by using a fraction of the original number of channels (i.e., 10 instead of 48), one can achieve the higher SN ratio.
- **In conclusion, it is recommended connecting (in parallel) five (5) consecutive MEMS microphones, which are spaced with a current interval of 0.752 cm, to become one channel. This will make the new channel spacing ($dx\text{-opt}$) become $5 \times 0.752 = 3.76$ cm. Considering the targeted thickness (H) range of the HMA layer [i.e., 4 cm (H_{\min}) – 20 cm (H_{\max})], the total length of the array (L) will have to be in 40 cm – 60 cm (i.e., 2 – 3 times of H_{\max}). A 10-channel array will then be too short (i.e., $L = 33.84$ cm). Instead, a 16-channel array seems to be a good number (i.e., $L = 56.4$ cm) that can also be more effective in handling other types of field challenges in comparison to the 10-channel array. The new receiver spacing ($dx\text{-opt} = 3.76$ cm) is smaller than the H_{\min} , meeting the required condition of the minimum receiver spacing ($\leq H$). If $4dx (= 3.008$ cm) is more favorable, instead of an odd number of $5dx$, from a hardware-design perspective, it ($4dx$) can also be used because the total array length ($L = 45.12$ cm) will still be in the optimum range.**
- **During the first half of the project execution, it is most critical to come up with a system that works best for one longitudinal array because the final system will be simply a transverse arrangement of multiple such arrays. In this sense, it may be a good idea to build a longer array of 32-channel that can be easily divided into two 16-channel arrays for various other testing purposes [e.g., resolution test in velocity (V_s) and thickness (H)].**
- **References Cited**
- *Park, C., 2016, MASW analysis of bedrock velocities (V_s and V_p): [Exp. Abs.] 86th Ann. Mtg. SEG, October 16-21, 2016, Dallas, Texas.*
- *Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., 1976, Applied Geophysics, Cambridge Univ. Press.*

SUMMARY [Simple Re-sampling (Decimation)]

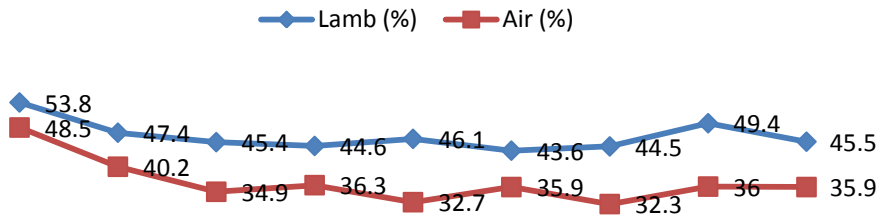
Table 1: Summary of testing parameters for the “simple re-sampling” case.

	1dx (48-CH)	2dx (24-CH)	3dx (16-CH)	4dx (12-CH)	5dx (10-CH)	6dx (8-CH)	7dx (7-CH)	8dx (6-CH)	12dx (4-CH)
Lamb Amp* (%)	53.8	47.4	45.4	44.6	46.1	43.6	44.5	49.4	45.5
Air Amp* (%)	48.5	40.2	34.9	36.3	32.7	35.9	32.3	36.0	35.9
Lamb/Air	1.11	1.17	1.30	1.23	1.41	1.21	1.38	1.37	1.27
V-Lamb** (m/sec)	2400	2400	2400	2360	2400	2400	2400	2440	2440
V-Air** (m/sec)	360	360	360	360	360	360	360	360	360

*Normalized amplitude (%) of Lamb and Air waves observed in the FRQ-Sum curve. Testing details are presented in Appendix I.

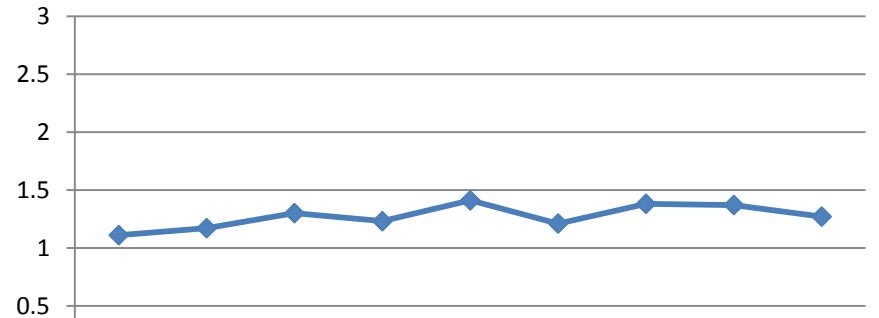
**Phase velocity of the peaks in the FRQ-Sum curve corresponding to Lamb and air waves. Testing details are presented in Appendix I.

Chart 1: Lamb/Air Wave Amplitude



(48-CH)	(24-CH)	(16-CH)	(12-CH)	(10-CH)	(8-CH)	(7-CH)	(6-CH)	(4-CH)
1dx	2dx	3dx	4dx	5dx	6dx	7dx	8dx	12dx

Chart 2: Lamb/Air Ratio



(48-CH)	(24-CH)	(16-CH)	(12-CH)	(10-CH)	(8-CH)	(7-CH)	(6-CH)	(4-CH)
1dx	2dx	3dx	4dx	5dx	6dx	7dx	8dx	12dx

SUMMARY (Stack-Re-sampling)

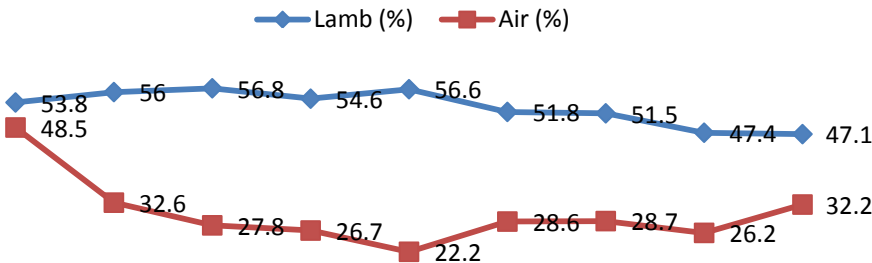
Table 2: Summary of testing results for the “stack-re-sampling” case.

	1dx (48-CH)	2dx (24-CH)	3dx (16-CH)	4dx (12-CH)	5dx (10-CH)	6dx (8-CH)	7dx (7-CH)	8dx (6-CH)	12dx (4-CH)
Lamb Amp* (%)	53.8	56.0	56.8	54.6	56.6	51.8	51.5	47.4	47.1
Air Amp* (%)	48.5	32.6	27.8	26.7	22.2	28.6	28.7	26.2	32.2
Lamb/Air	1.11	1.72	2.04	2.04	2.55	1.81	1.79	1.81	1.46
V-Lamb** (m/sec)	2400	2360	2360	2360	2400	2360	2400	2360	2400
V-Air** (m/sec)	360	360	360	360	360	360	360	400	360

*Normalized amplitude (%) of Lamb and Air waves observed in the FRQ-Sum curve. Testing details are presented in Appendix II.

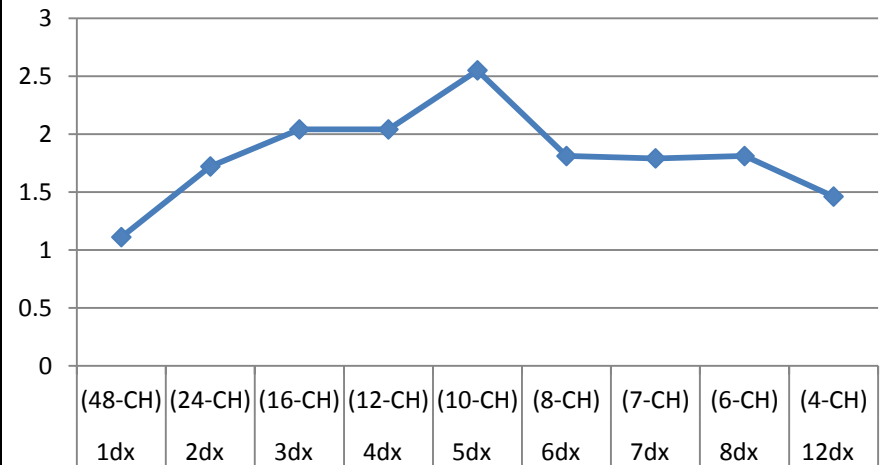
**Phase velocity of the peaks in the FRQ-Sum curve corresponding to Lamb and air waves. Testing details are presented in Appendix II.

Chart 3: Lamb/Air Wave Amplitude



(48-CH)	(24-CH)	(16-CH)	(12-CH)	(10-CH)	(8-CH)	(7-CH)	(6-CH)	(4-CH)
1dx	2dx	3dx	4dx	5dx	6dx	7dx	8dx	12dx

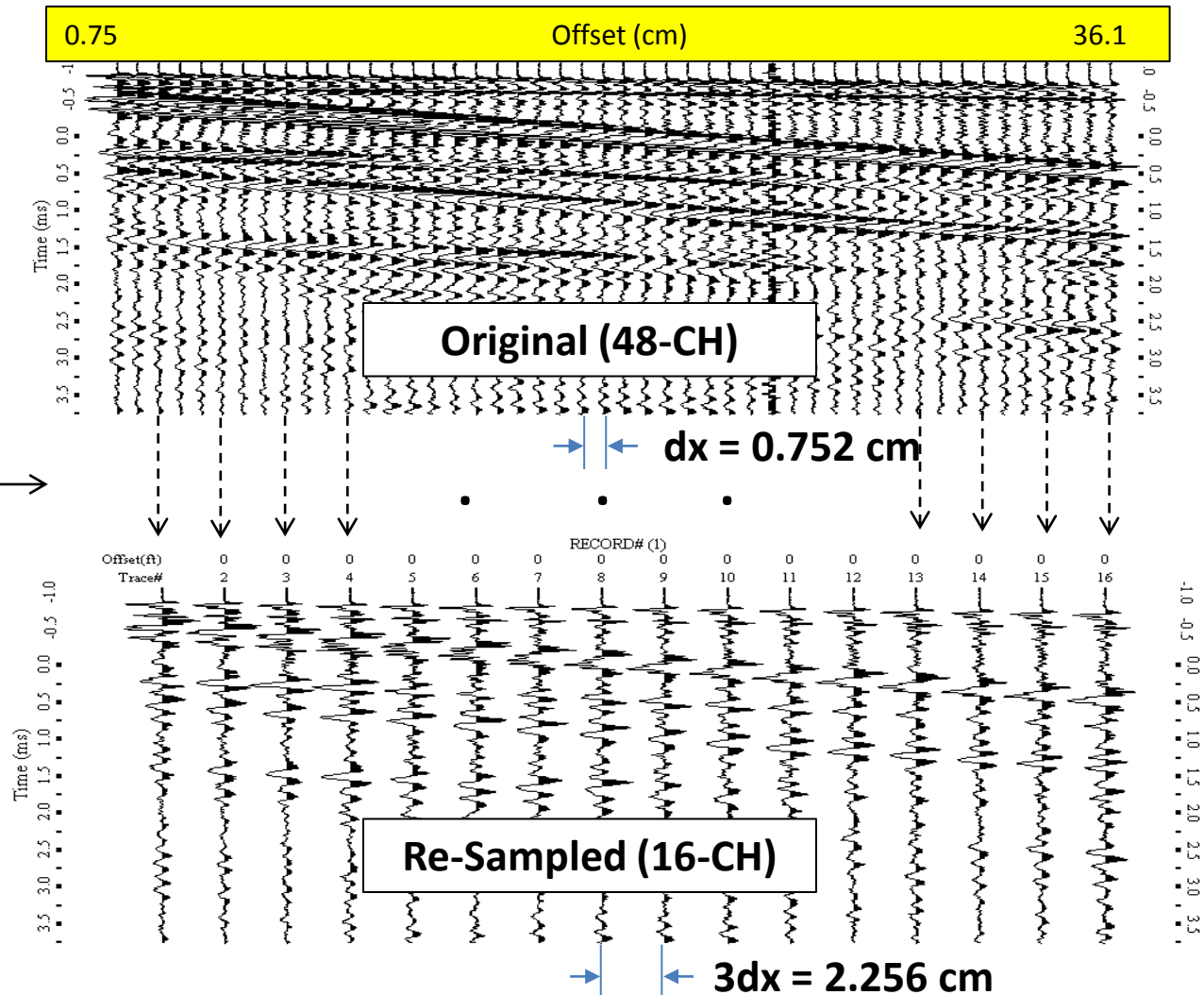
Chart 4: Lamb/Air Ratio



Simple Re-sampling (Decimation)

This type of spatial re-sampling is the simplest form among all possible options. The following is an example of re-sampling every 3rd trace (receiver) from the original field record of 48-channel acquisition with a channel spacing (dx) of 0.752 cm.

All traces in-between re-sampled ones are simply discarded (decimated).



Stack-Re-sampling

Certain number of consecutive traces (e.g., 3 traces) are stacked first and then the stacked trace is selected as the re-sampled trace. The following is an example of stack-re-sampling a set of 3 traces (receivers) from the original field record of 48-channel acquisition with a channel spacing (dx) of 0.752 cm.

A set of 3 consecutive traces are stacked to make one re-sampled trace.

