# MSU's Analog Digitization challenges

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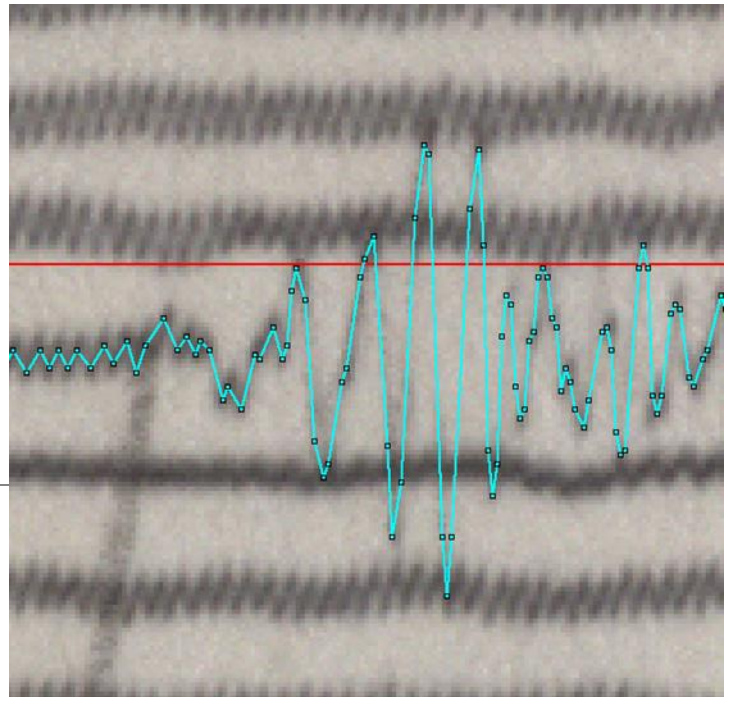


# Overview

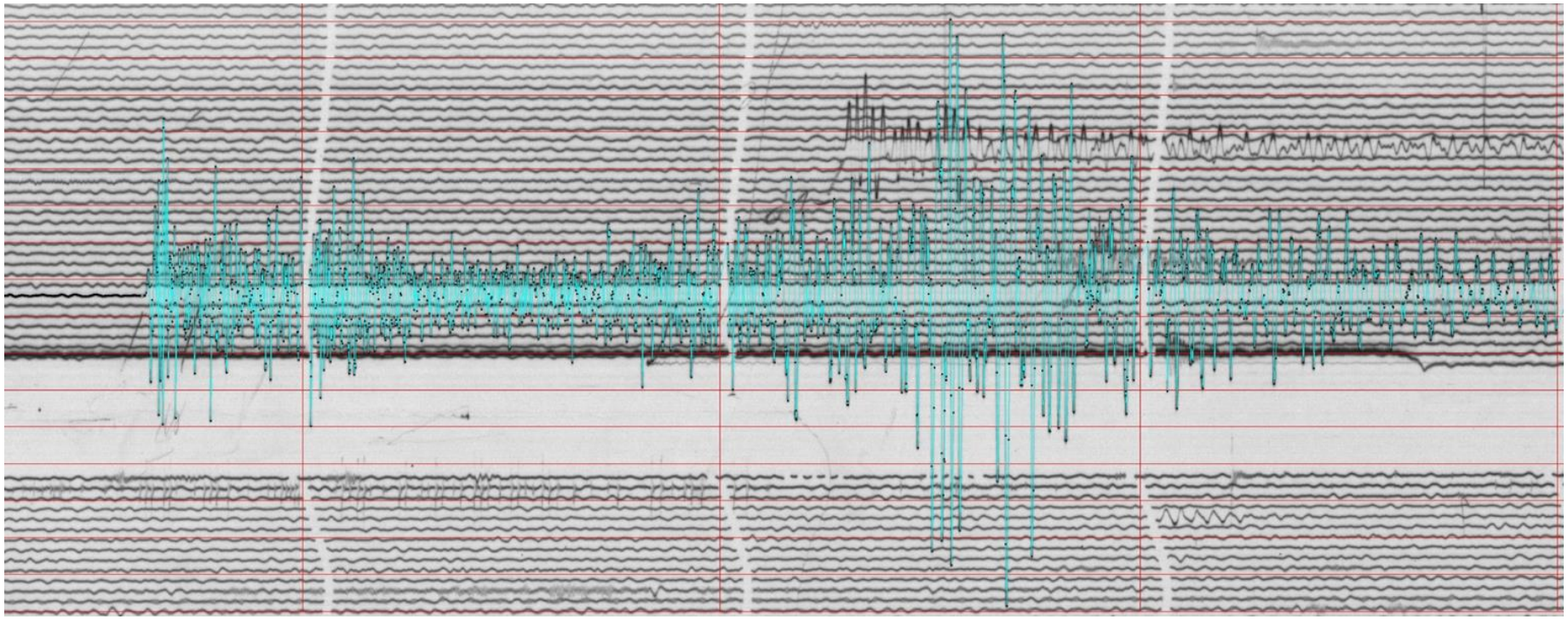
Digitization challenges

- Scan Resolution
- Exposure issues

Removing Station response from the digitized paper seismogram

- Convert base parameters into a response curve
- Match response curve to an equivalent poles & zeros estimation
- Ongoing research is figure out how to apply these response curves to the finished vectorized signal

# Seismogram Digitization Using WaveTrac Software

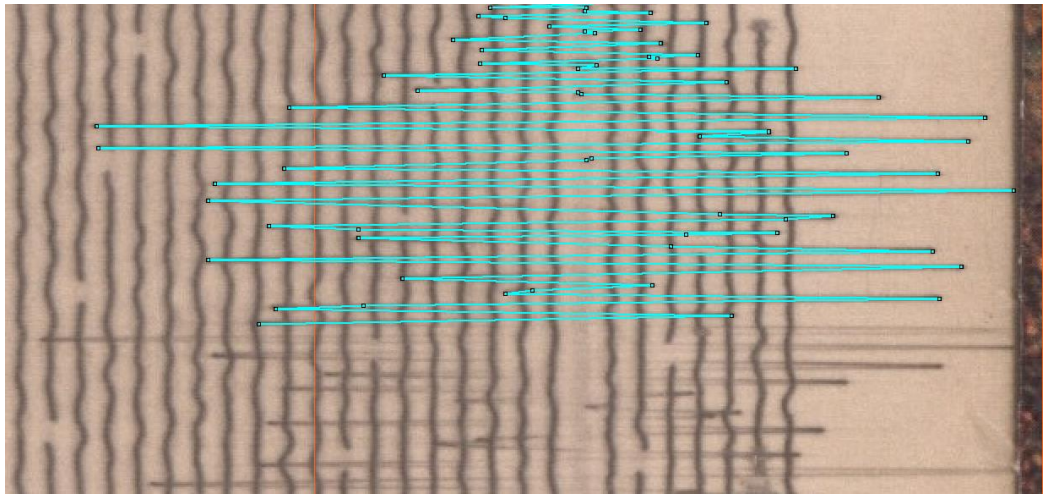


Digitization process showing the vertical component of the Neva 2-2 PNE as recorded at Ust'Nyukzha (746 km distant)

# Digitization challenges from physics

## High Amplitude & velocity

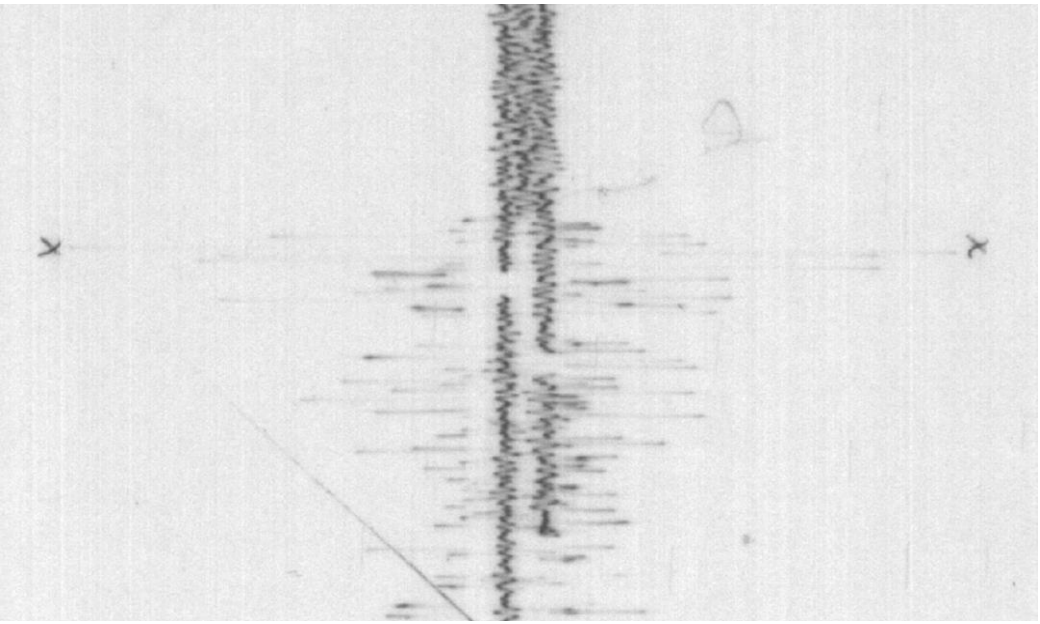
- The photopaper is exposure sensitive; Therefore fast-velocity light beams make a fainter and thinner record than slow-moving or stationary beams at the top & bottom of the peak. Signals also cross adjacent time records and sometimes travel off the edge of the paper. Amplitudes may therefore be clipped.



# Digitization challenges from process

## Scan Resolution & exposure

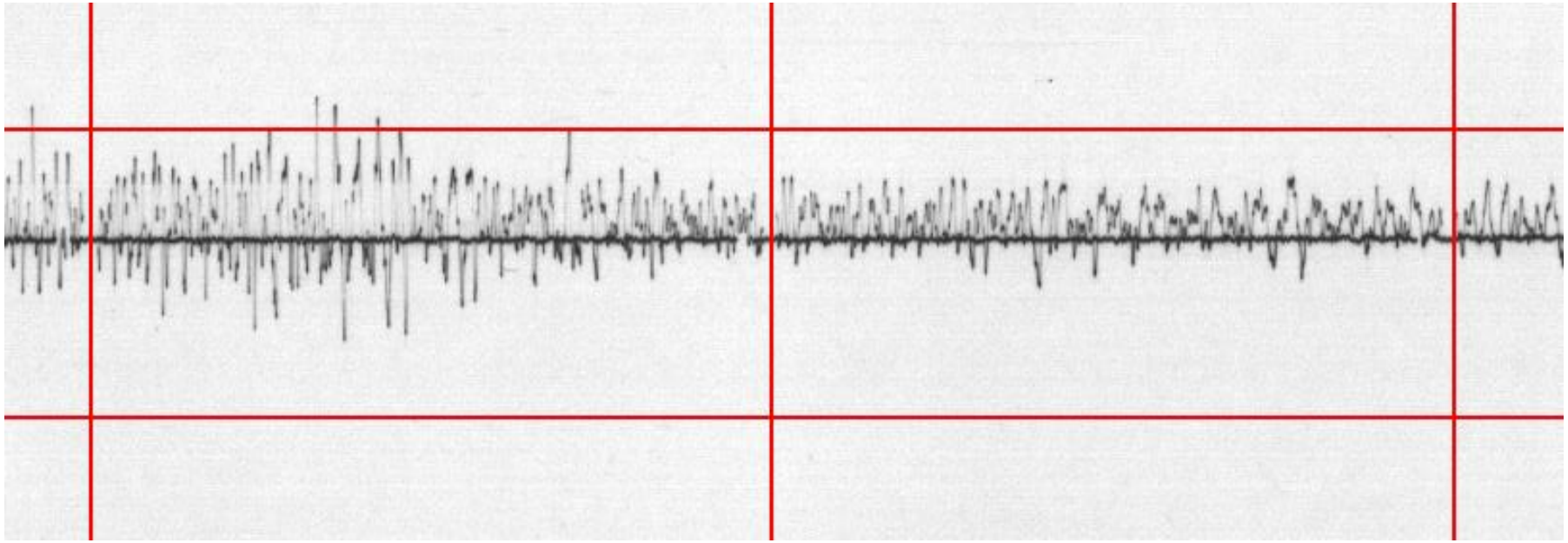
- Scan resolution less than 600 dpi are insufficient for capturing accurate waveforms and higher-frequency (>1Hz) are lost. Additionally, high-velocity light beams with faded traces are lost in the scan. Contrast control is critical.



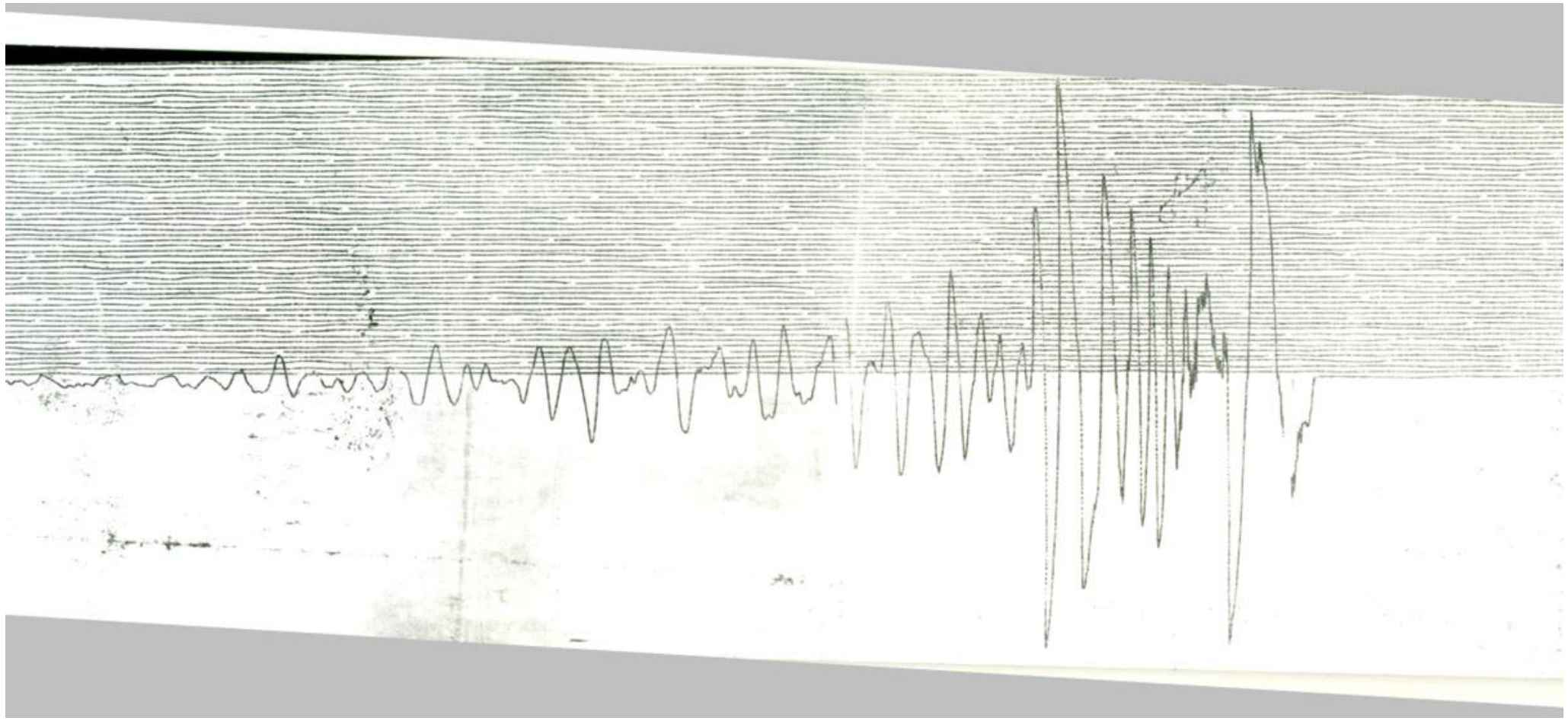
600dpi * (30mm/minute/25.4inches) /60 sec = 11.8 dots per second
= less than 6 Hz freq. resolution = about 1 Hz amplitude resolution at 5x oversampling ratio.

# Distortions from Minute Marks & drum speed variation

Soviet records break on the minute for one second; Two seconds on the even hour. Also, a minute might not be the same length as the previous minute. Wavetrack corrects for varying drum velocities.

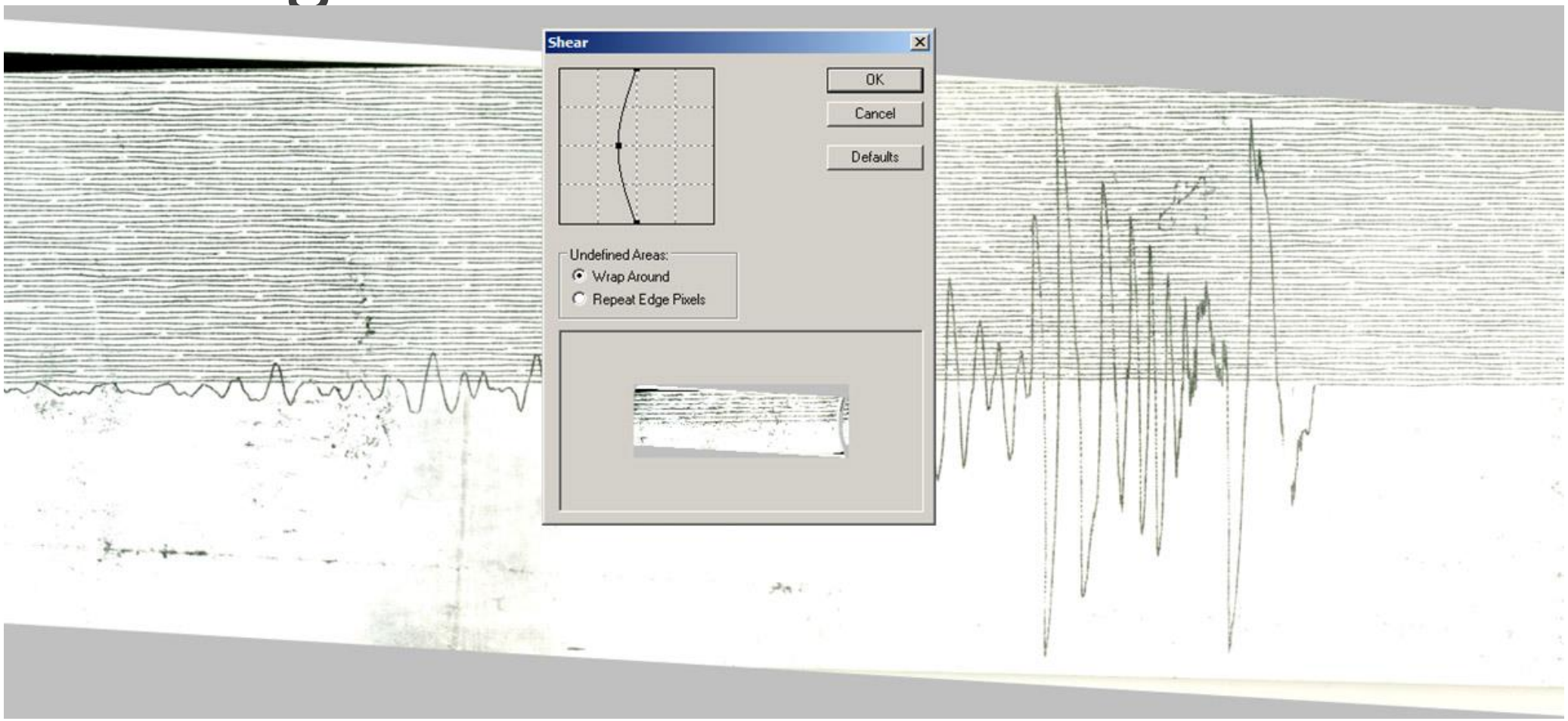


# Curvilinear Strong Motion Seismograms



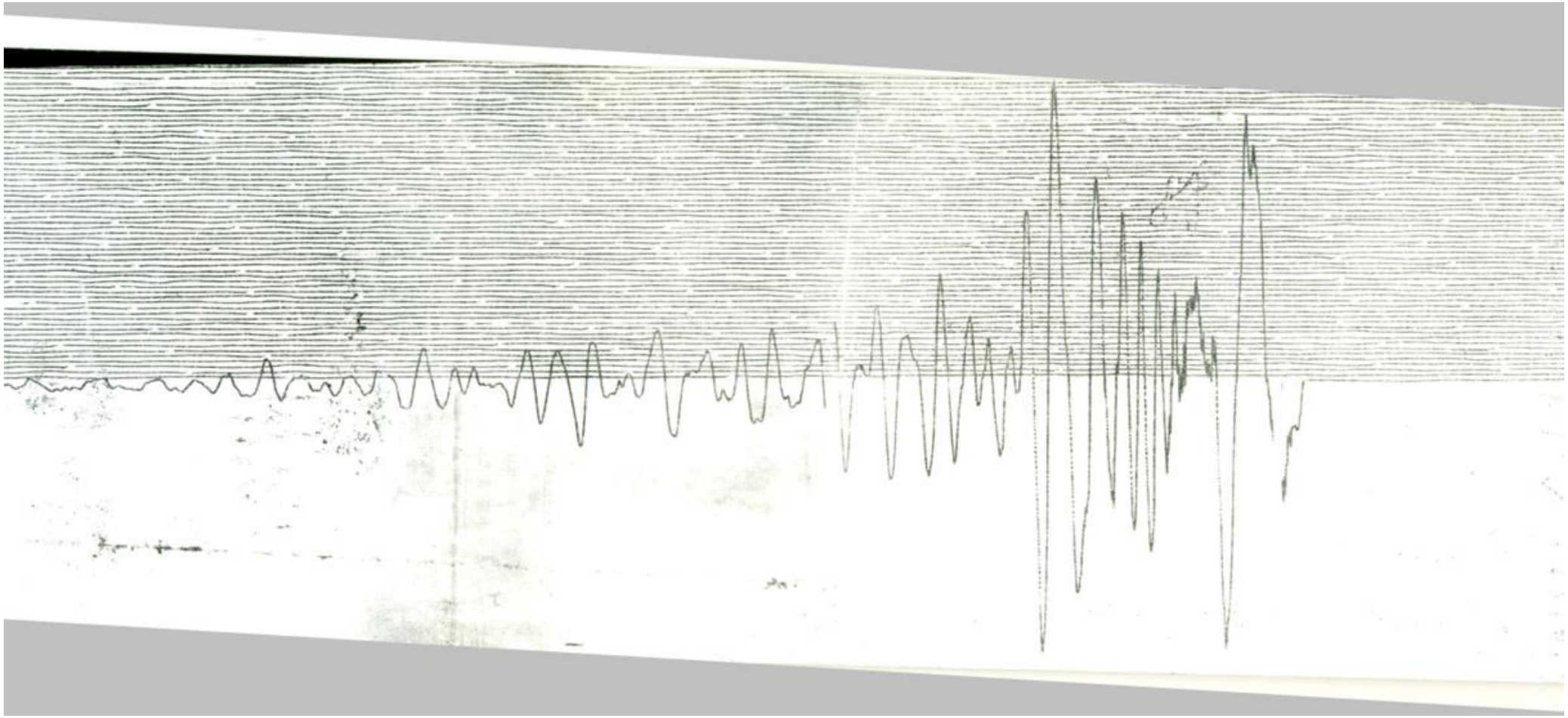
Cannot be digitized because the time scale shifts as a function of amplitude.

# Correction Process of Curvilinear Seismogram

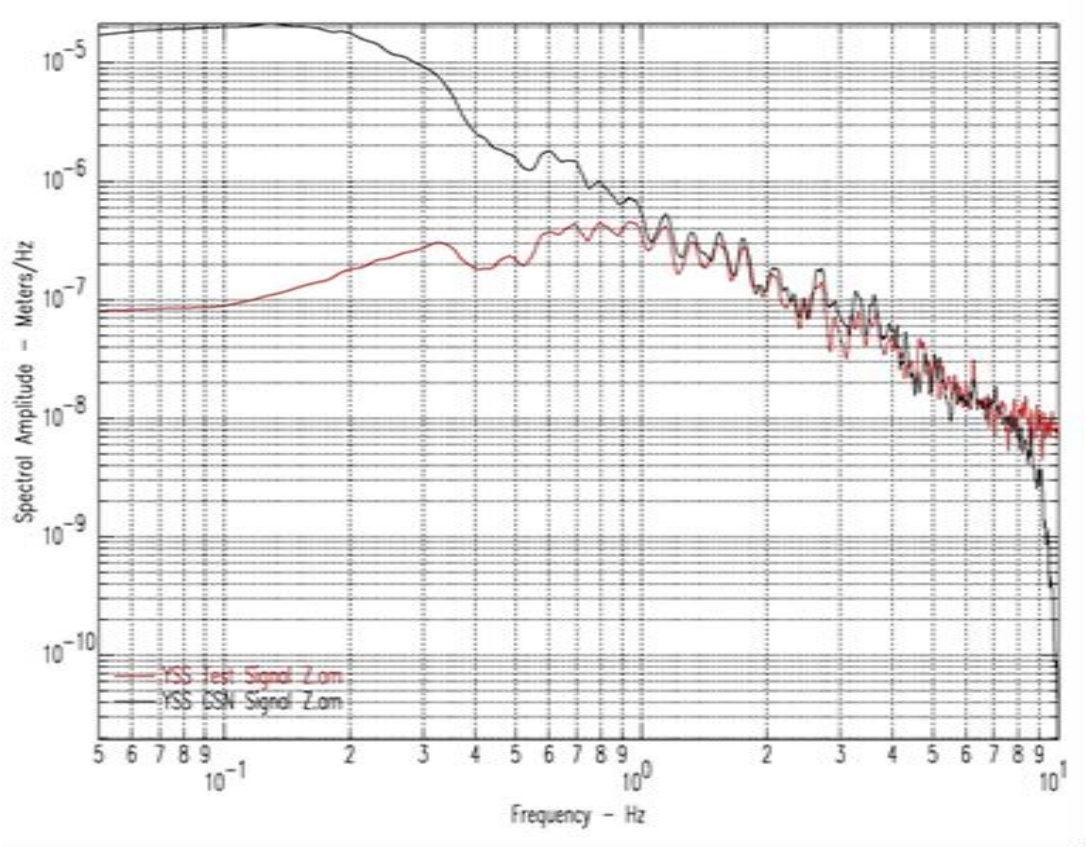


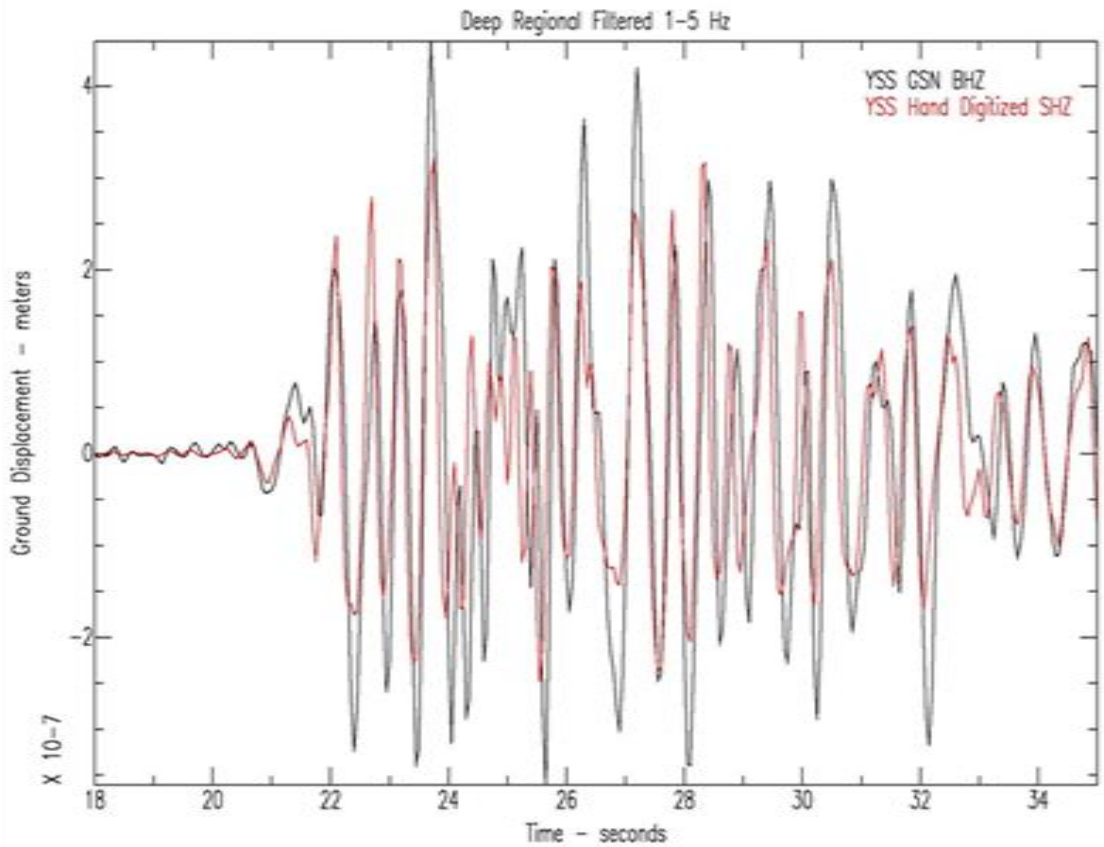

The seismogram can be corrected using the 'Shear' tool on Photoshop

# Corrected Seismogram



# Digitization Quality



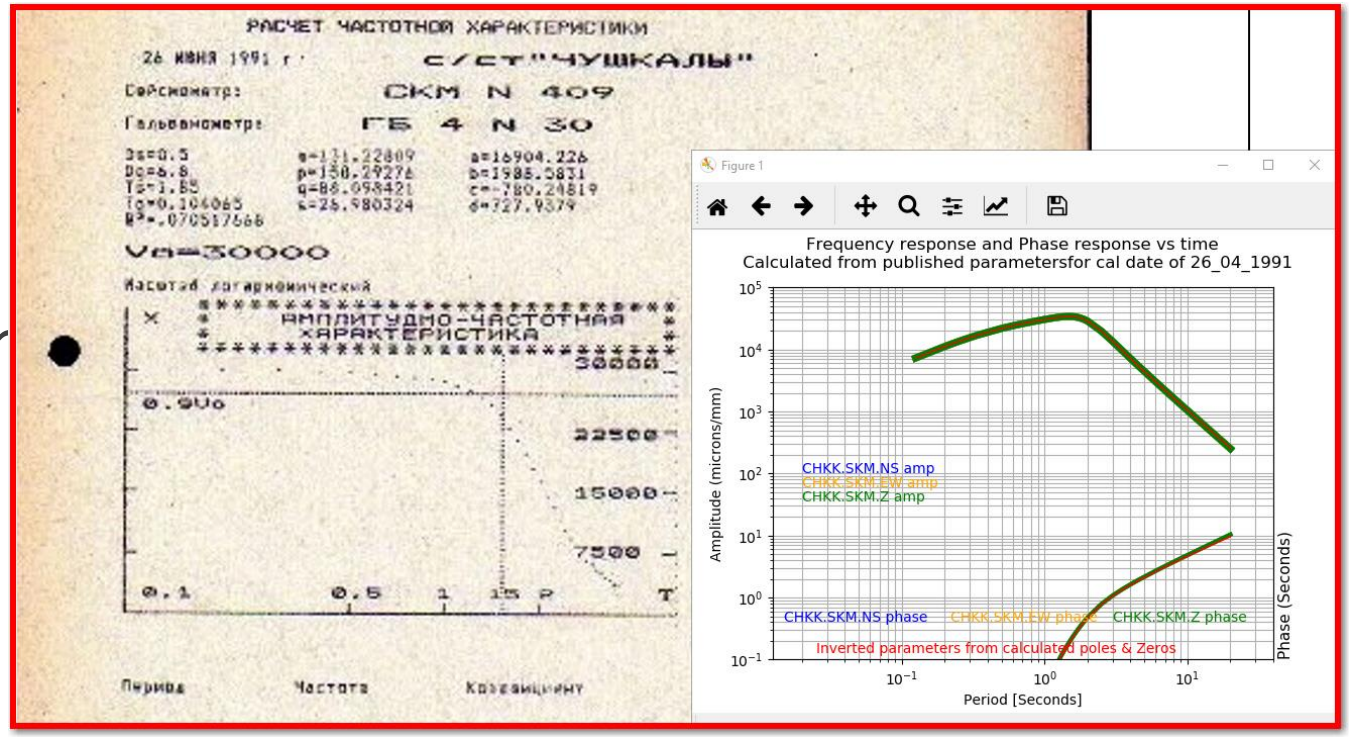




Analysis of frequency response of co-located digital station with analog station and the subsequent digitization of the analog record showed that it was possible to recover signals up to 5 – 8 Hz.

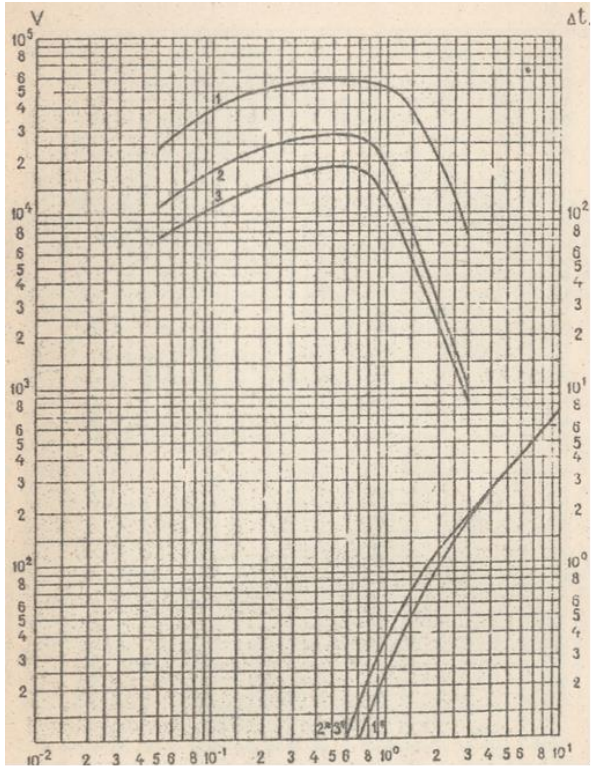
# Efforts to remove station response from a digitized analog seismogram

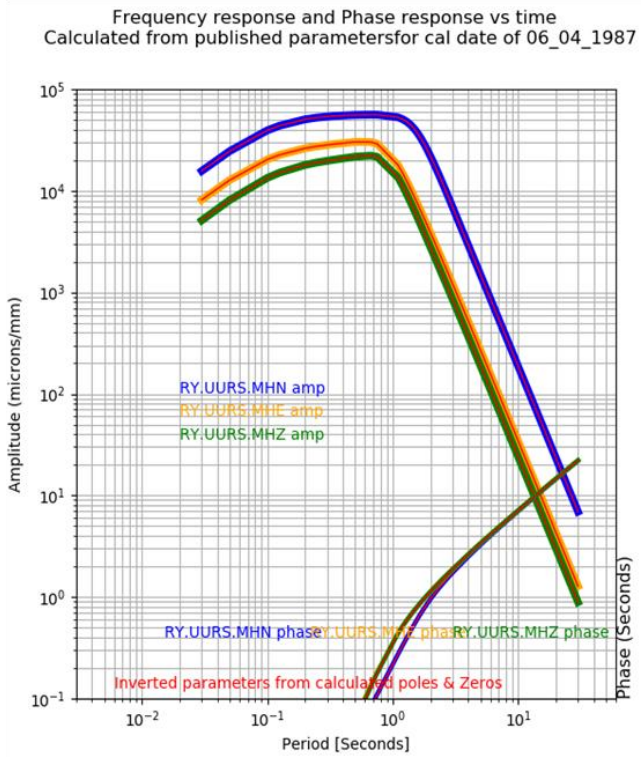
FSU analog stations used sound, “cookbook” calibration methods to derive instrument response.

These calibrations provided ar estimate of displacement amplification (unitless) between seismometer mass movement to light beam deflection on the paper.



# Resolving calibrations for legacy stations in the former USSR



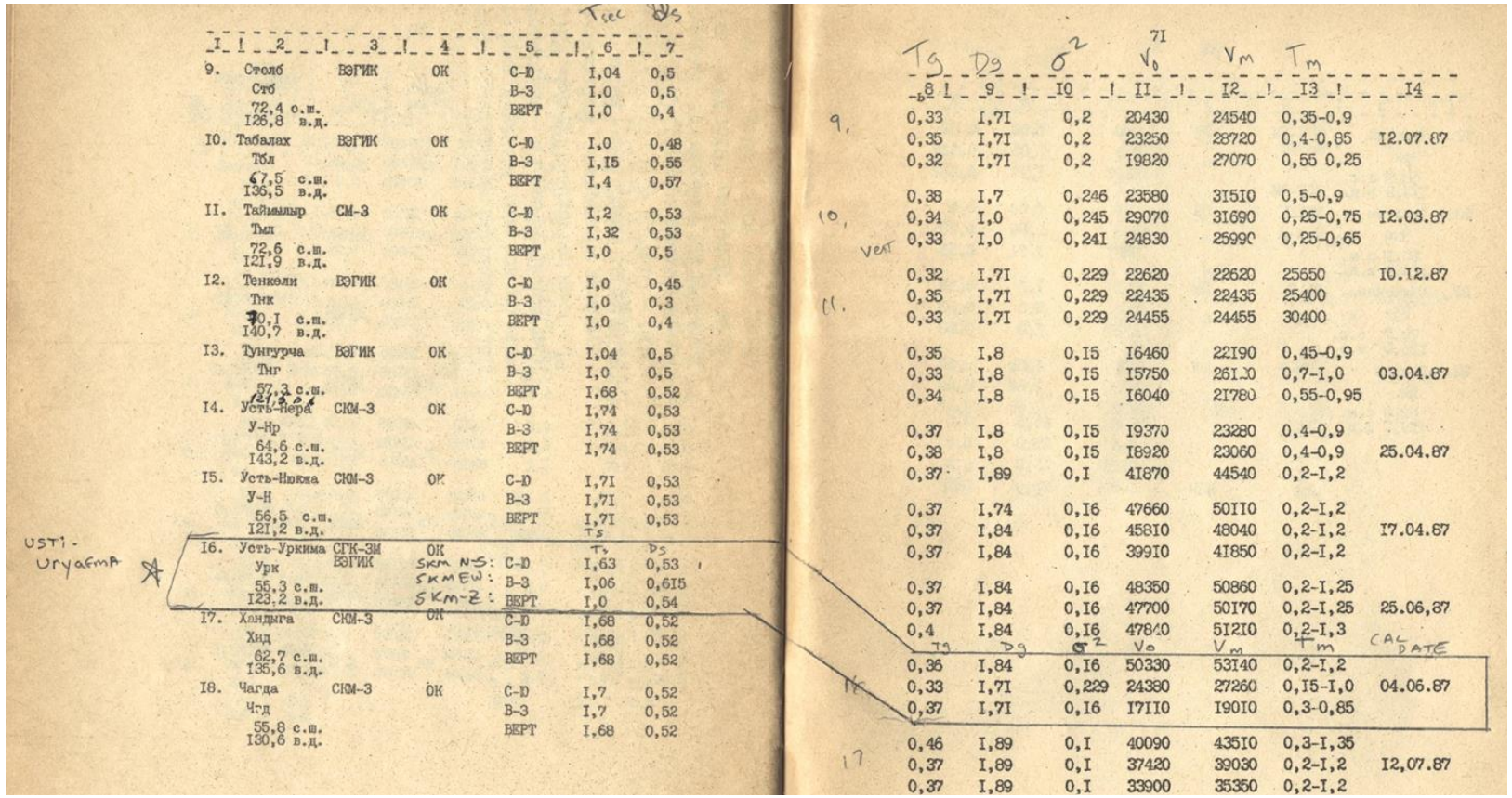
# Base calibration parameters for a Soviet analog channel

Ts, Ds: Resonance & Damping of signal coil

Tg,Dg: Resonance & Damping of galvo

$\sigma^2$ : Coupling coefficient

Vm: Maximum magnification



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| 9. | Столб | ВЭГИК | ОК | С-Ю | I,04 | 0,5 |
| | Стб | | | В-З | I,0 | 0,5 |
| | 72,4 с.ш. I26,8 в.д. | | | ВЕРТ | I,0 | 0,4 |
| I0. | Табалах | ВЭГИК | ОК | С-Ю | I,0 | 0,48 |
| | Тбл | | | В-З | I,I5 | 0,55 |
| | 67,5 с.ш. I36,5 в.д. | | | ВЕРТ | I,4 | 0,57 |
| II. | Таймылыр | СМ-3 | ОК | С-Ю | I,2 | 0,53 |
| | Тмл | | | В-З | I,32 | 0,53 |
| | 72,6 с.ш. I2I,9 в.д. | | | ВЕРТ | I,0 | 0,5 |
| I2. | Тенкели | ВЭГИК | ОК | С-Ю | I,0 | 0,45 |
| | Тнк | | | В-З | I,0 | 0,3 |
| | 70,I с.ш. I40,7 в.д. | | | ВЕРТ | I,0 | 0,4 |
| I3. | Тунгурча | ВЭГИК | ОК | С-Ю | I,04 | 0,5 |
| | Тнг | | | В-З | I,0 | 0,5 |
| | 57,3 с.ш. | | | ВЕРТ | I,68 | 0,52 |
| I4. | Усть-Нера | СКМ-3 | ОК | С-Ю | I,74 | 0,53 |
| | У-Нр | | | В-З | I,74 | 0,53 |
| | 64,6 с.ш. I43,2 в.д. | | | ВЕРТ | I,74 | 0,53 |
| I5. | Усть-Нюкжа | СКМ-3 | ОК | С-Ю | I,7I | 0,53 |
| | У-Н | | | В-З | I,7I | 0,53 |
| | 56,5 с.ш. I2I,2 в.д. | | | ВЕРТ | I,7I | 0,53 |
| I6. | Усть-Уркима | СГК-3М ВЭГИК | ОК 5km N-S: 5km E-W: 5km-Z: | С-Ю | I,63 | 0,53 |
| | Урк | | | В-З | I,06 | 0,6I5 |
| | 55,3 с.ш. I23,2 в.д. | | | ВЕРТ | I,0 | 0,54 |
| I7. | Хандыга | СКМ-3 | ОК | С-Ю | I,68 | 0,52 |
| | Хнд | | | В-З | I,68 | 0,52 |
| | 62,7 с.ш. I35,6 в.д. | | | ВЕРТ | I,68 | 0,52 |
| I8. | Чагда | СКМ-3 | ОК | С-Ю | I,7 | 0,52 |
| | Чгд | | | В-З | I,7 | 0,52 |
| | 55,8 с.ш. I30,6 в.д. | | | ВЕРТ | I,68 | 0,52 |

USTI-Uryafma

| | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|
| 9. | 0,33 | I,7I | 0,2 | 20430 | 24540 | 0,35-0,9 | |
| | 0,35 | I,7I | 0,2 | 23250 | 28720 | 0,4-0,85 | I2.07.87 |
| | 0,32 | I,7I | 0,2 | I9820 | 27070 | 0,55 0,25 | |
| | 0,38 | I,7 | 0,246 | 23580 | 3I5I0 | 0,5-0,9 | |
| 10. | 0,34 | I,0 | 0,245 | 29070 | 3I690 | 0,25-0,75 | I2.03.87 |
| VERT | 0,33 | I,0 | 0,24I | 24830 | 25990 | 0,25-0,65 | |
| | 0,32 | I,7I | 0,229 | 22620 | 22620 | 25650 | I0.I2.87 |
| 11. | 0,35 | I,7I | 0,229 | 22435 | 22435 | 25400 | |
| | 0,33 | I,7I | 0,229 | 24455 | 24455 | 30400 | |
| | 0,35 | I,8 | 0,I5 | I6460 | 22I90 | 0,45-0,9 | |
| | 0,33 | I,8 | 0,I5 | I5750 | 26I00 | 0,7-I,0 | 03.04.87 |
| | 0,34 | I,8 | 0,I5 | I6040 | 2I780 | 0,55-0,95 | |
| | 0,37 | I,8 | 0,I5 | I9370 | 23280 | 0,4-0,9 | |
| | 0,38 | I,8 | 0,I5 | I8920 | 23060 | 0,4-0,9 | 25.04.87 |
| | 0,37 | I,89 | 0,I | 4I870 | 44540 | 0,2-I,2 | |
| | 0,37 | I,74 | 0,I6 | 47660 | 50II0 | 0,2-I,2 | |
| | 0,37 | I,84 | 0,I6 | 458I0 | 48040 | 0,2-I,2 | I7.04.87 |
| | 0,37 | I,84 | 0,I6 | 399I0 | 4I850 | 0,2-I,2 | |
| | 0,37 | I,84 | 0,I6 | 48350 | 50860 | 0,2-I,25 | |
| | 0,37 | I,84 | 0,I6 | 47700 | 50I70 | 0,2-I,25 | 25.06,87 |
| | 0,4 | I,84 | 0,I6 | 47840 | 5I2I0 | 0,2-I,3 | |
| | Tg | Dg | $\sigma^2$ | $V_0$ | $V_m$ | $T_m$ | CALDATE |
| | 0,36 | I,84 | 0,I6 | 50330 | 53I40 | 0,2-I,2 | |
| 16 | 0,33 | I,7I | 0,229 | 24380 | 27260 | 0,I5-I,0 | 04.06.87 |
| | 0,37 | I,7I | 0,I6 | I7II0 | I90I0 | 0,3-0,85 | |
| | 0,46 | I,89 | 0,I | 40090 | 435I0 | 0,3-I,35 | |
| 17 | 0,37 | I,89 | 0,I | 37420 | 39030 | 0,2-I,2 | I2,07.87 |
| | 0,37 | I,89 | 0,I | 33900 | 35350 | 0,2-I,2 | |

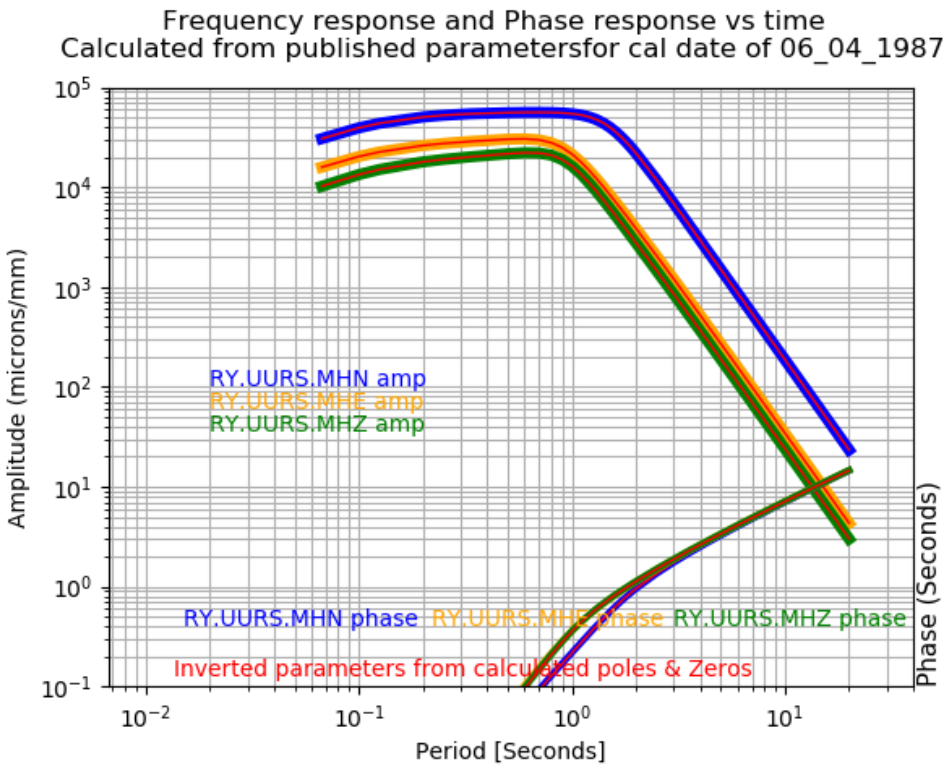
# Base parameters are converted to a pole/zero estimate of magnification. (Pzcalc.py)

For channel RY.UURS.MHZ:

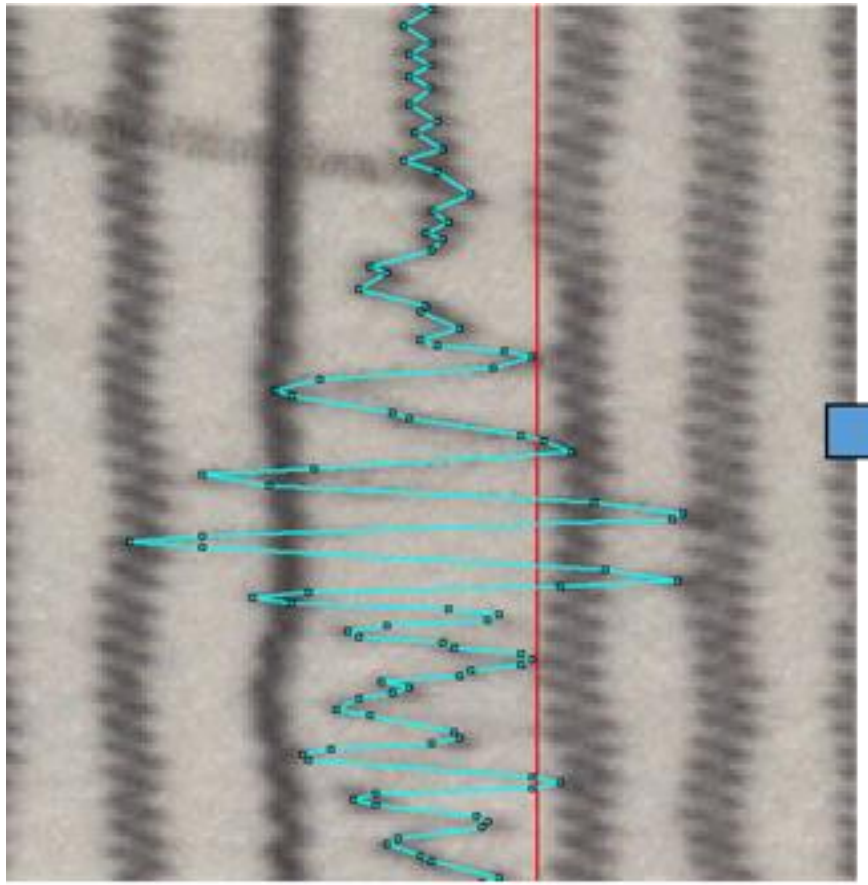
ZEROS 6
0.000000e+00 0.000000e+00
0.000000e+00 0.000000e+00
-2.877372e+01 0.000000e+00
-6.572467e-03 0.000000e+00
5.786433e+02 0.000000e+00

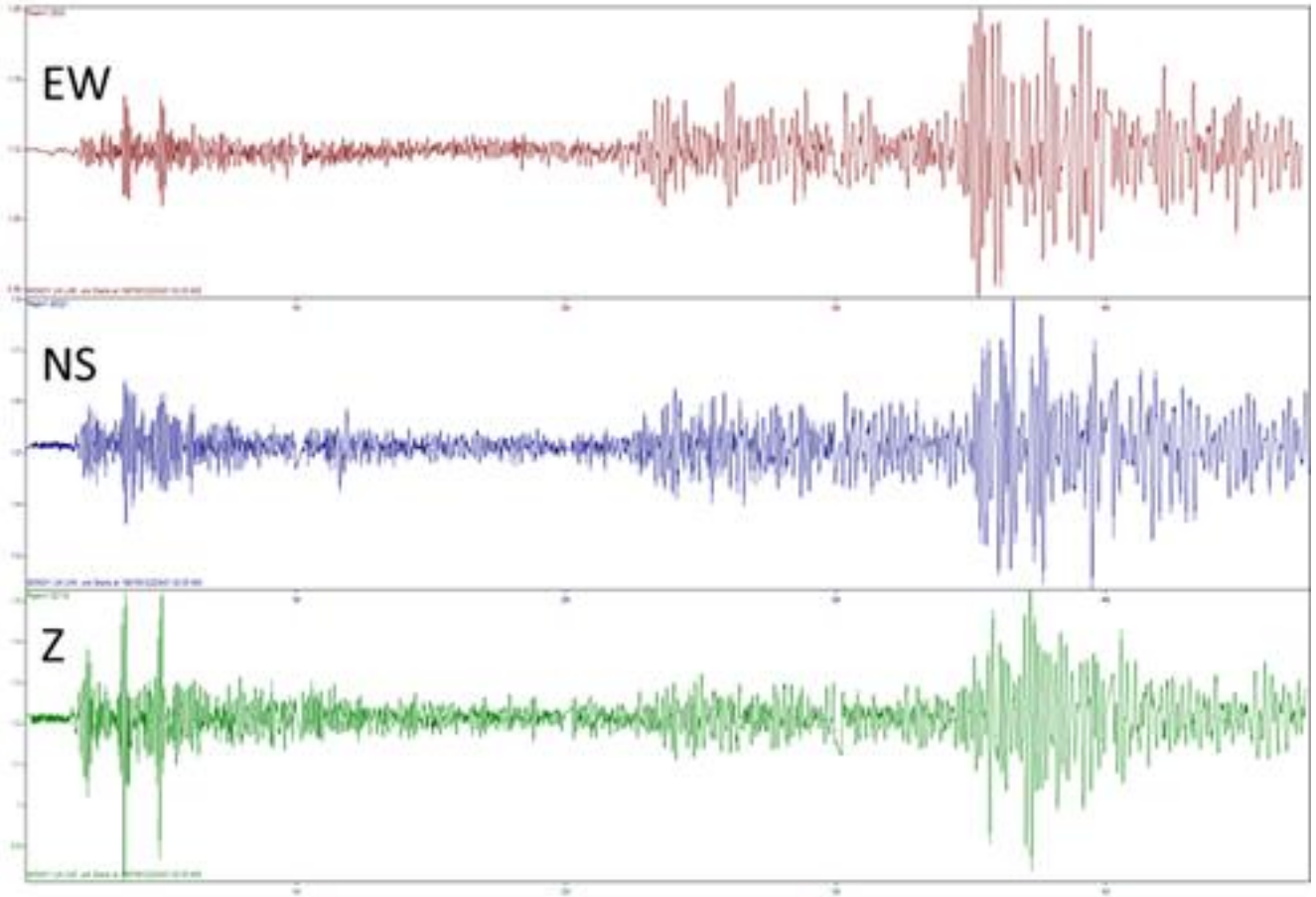
POLES 5
-3.124741e+00 6.045601e+00
-3.124741e+00 -6.045601e+00
-4.517898e+00 0.000000e+00
-5.213242e+01 0.000000e+00
-2.939767e+01 0.000000e+00

AO Normalization factor 8.470479e-02
Sensitivity 22117.6
Sensitivity frequency = 1.67 Hz
Evaluation factor for this estimate (Less than 12 is good): 2.5



# Next challenge: Adding in the effects of seismogram digitization to the calibration





# Dan’s Current issues

How to apply the effects of seismogram rasterization to the station response

- DPI = Sample rate and digitizer resolution

How to apply the effects of seismogram vectorization to response?

- Effects of hand-digitizing can be subtle, with the unintentional introduction of high-frequency artifacts

Seismograms are records of DISPLACEMENT. Most digitized records represent VELOCITY. How do we handle this when making the final pole/zero solution for the dataless SEED/resp file?