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MEASUREMENTS OF VIBRATIONS FROM QUARRY EXPLOSIONS AT TWO SITES NEARBY TŪRKALNE QUARRY IN LATVIA

REPORT

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Vilnius 2013

Introduction

Currently The Client quarries the lode Tūrkalne in Latvia, Ropazi municipality. Chemical explosions are used to crumble hard rock in the process of extraction of rock.

Two major goals were set for this investigation. The first one was to measure vibrations originated by explosions at Tūrkalne quarry at two steadings – "Paltes" (N1) and "Piparini" (N2), and to check if the vibrations didn't exceed maximum allowed limits of standard DIN 4150. The second goal was to investigate what level of vibrations could be expected at the same two steadings (N1 and N2) when explosions would be carried out at new Areni lode and new Kalnagraviši lode.

Maximum allowed vibrations

Maximum allowed vibrations originated from explosions are defined by standard DIN 4150 part 3 (table 1). The measured vibrations had to comply with the second line of the table 1 as sites of interest were steadings with dwellings.

Table 1. Maximum allowed velocity of vibrations for different types of buildings according to standard DIN 4150.

Type of structure		*Maximum allowed velocity of vibrations, mm/s*			
		Frequency			*All frequencies*
		1-10 Hz	*10-50 Hz*	*50-100 Hz*	
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20-40	40-50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5-15	15-20	15
3	Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	3	3-8	8-10	8

Setting of measurements of vibrations caused by quarry explosions

Setting of explosions and measurement points are shown in the figure 1. Data about explosions are provided in the table 2. Data about locations of seismic measurement equipment are provided in the table 3. Photos from measurement point N1 and N2 are provided in figures 2 and 3. Schemes of settings of explosions 1 and 2 are provided in figures 4 and 5.

Table 2. Locations and parameters of explosions.

Parameters of explosions	**Explosion 1**	**Explosion 2**
Date	2013.06.19	2013.06.19
Time (local)	16:06	16:19
Easting UTM WGS84, zone 35N, m	360254	360330
Northing UTM WGS84, zone 35N, m	6309754	6309754
Geographic latitude	56° 54' 37.33" N	56° 54' 37.412" N
Geographic longitude	24° 42' 17.429" E	24° 42' 21.952" E
Charge of explosion, kg	870	3210
Number of boreholes	29	80

Table 3. Locations of measurement points.

Parameters of measurement points	**Measurement point 1**	**Measurement point 2**
Instrument type	SARA SL07	SARA SL07
Sensor type	4.5 Hz geophone	4.5 Hz geophone
Number of components	3 (Z, N, E)	3 (Z, N, E)
Serial number	s/n-598	s/n-599
Name of portative seismic station	LGS2	LGS4
Easting UTM WGS84, zone 35N, m	357868	357416
Northing UTM WGS84, zone 35N, m	6310043	6309833
Geographic latitude	56° 54' 44.079" N	56° 54' 36.794" N
Geographic longitude	24° 39' 55.949" E	24° 39' 29.632" E
Distance from measurement point 1, km	2.403	2.478
Distance from measurement point 2, km	2.839	2.915

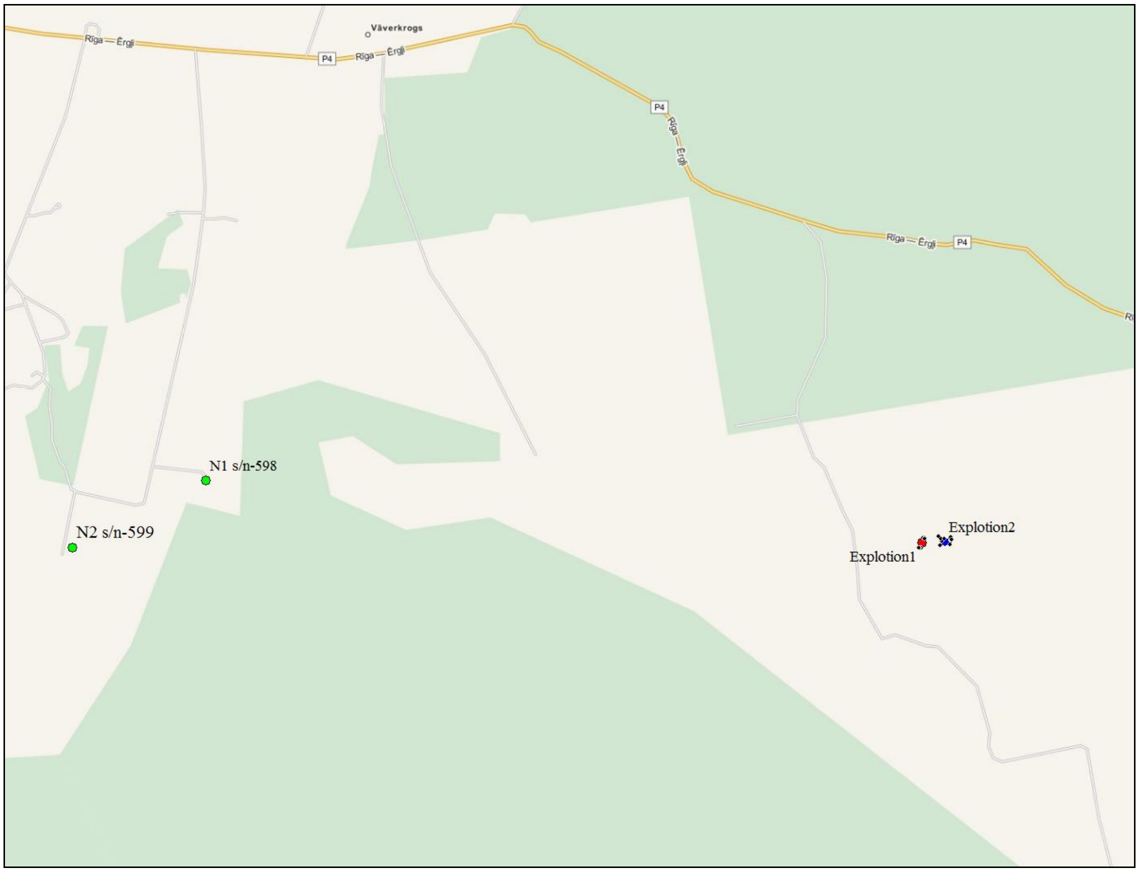


Figure 1. Setting of explosions and measurement points. Red and blue points indicate explosion points „Explosion 1“ and „Explosion 2“, green points correspond to measurement points N1 and N2.

Figure 2. Measurements of soil trembling from quarry explosion at steading N1

Figure 3. Measurements of soil trembling from quarry explosion at steading N2

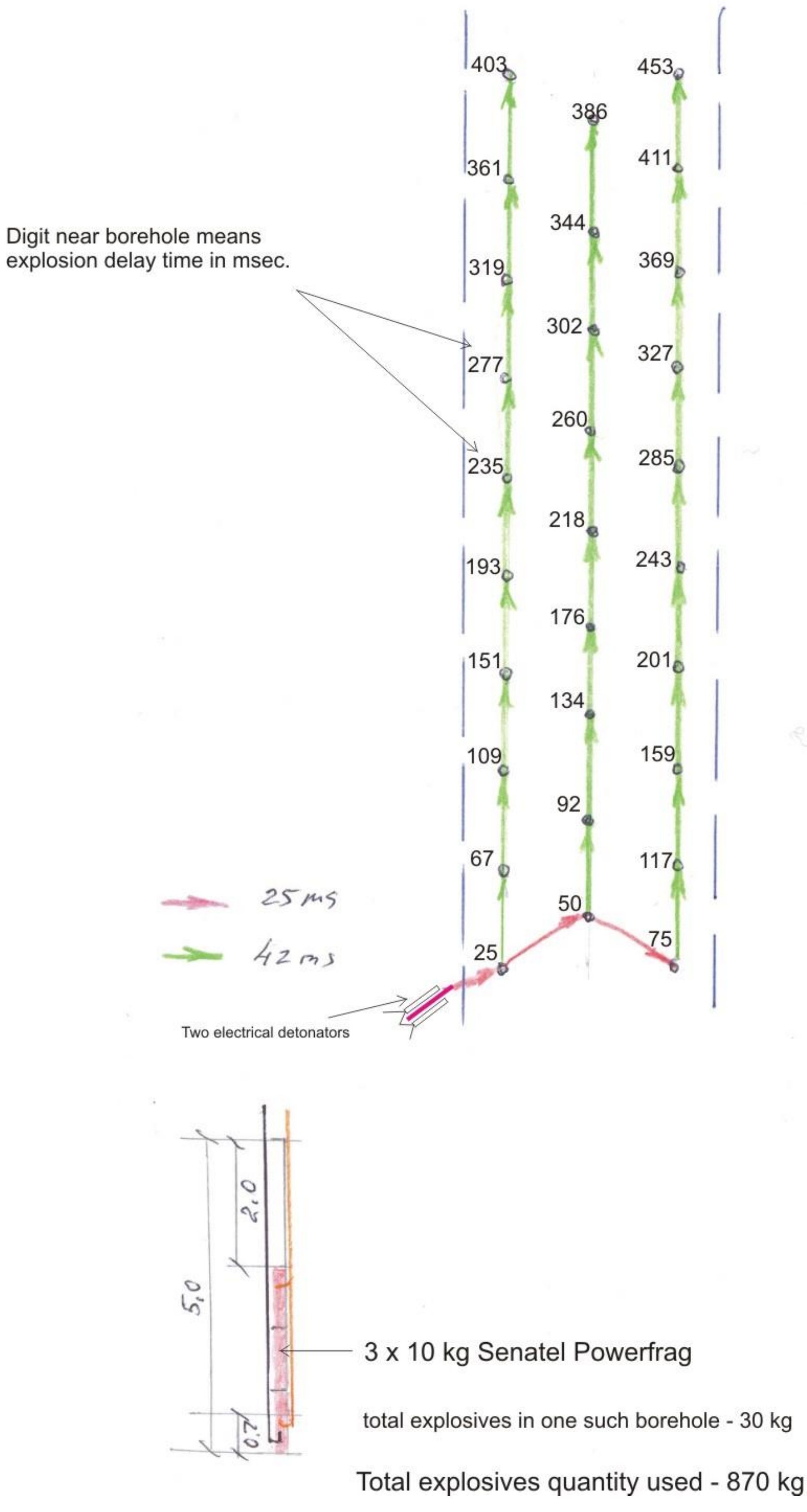


Figure 4. Scheme of setting of explosion 1.

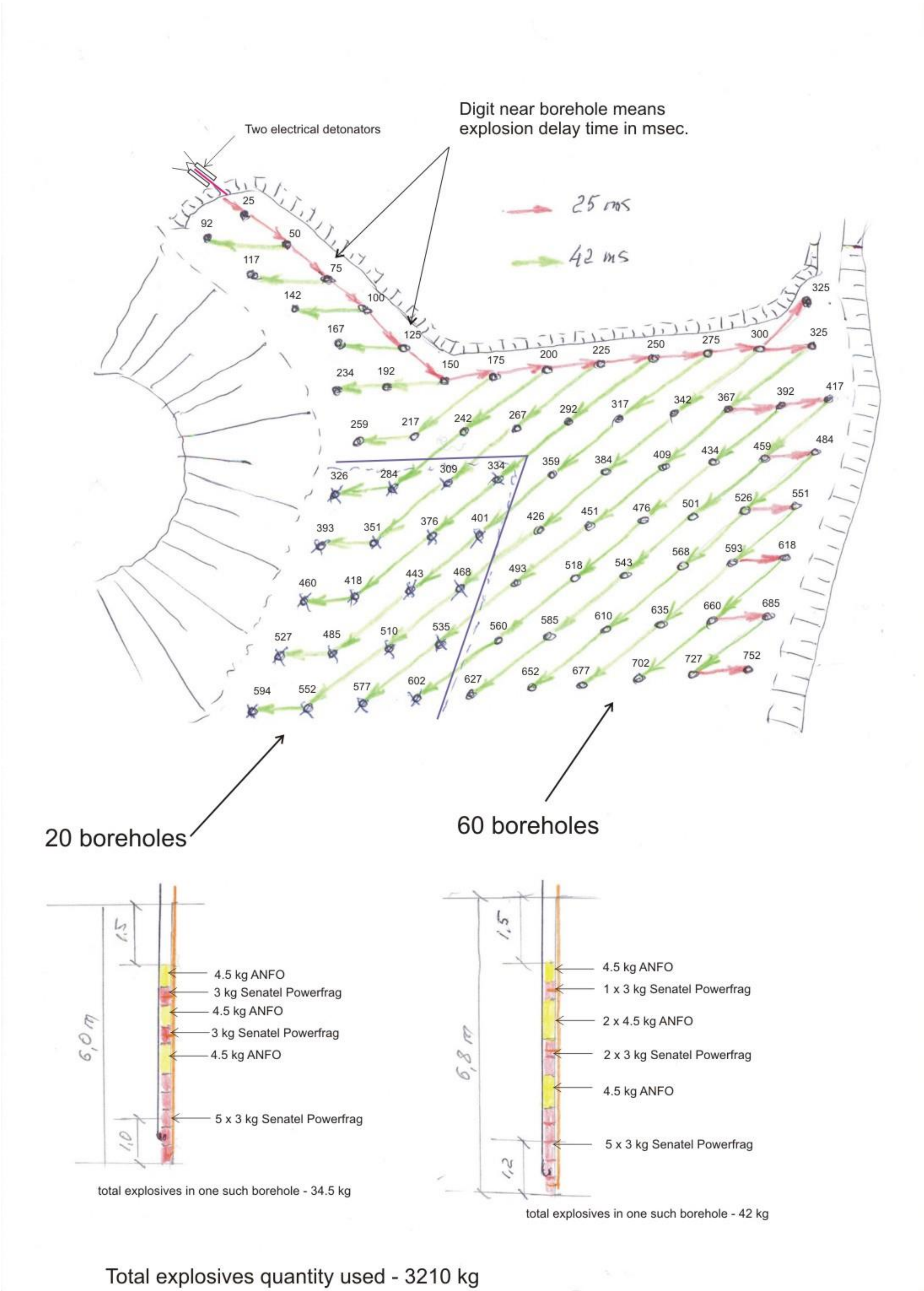


Figure 5. Scheme of setting of explosion 2.

Equipment used for measurements

Two units of portative seismic stations SARA SL07 (http://www.sara.pg.it/documenti/sl07_datasheet_eng.pdf) were used to measure intensity of vibrations at measurement points N1 and N2. Portative seismic station SL07 consist of 24 bit digitizer, integrated 3 component 4.5 Hz geophones, management module and SD memory card. Seismograms or history of vibration is written into seisan format files. Recorded files are processed using SEISAN 9.1.1 software suite (http://www.uib.no/rg/geodyn/artikler/2010/02/software).

Constant monitoring f seismic trembling is performed near dolomite quarry Petrasiunai II in Lithuania. Two different sets of measurement equipment were installed near Petrasiunai II quarry on May of 2012. The first set was portative seismic station SL07 by SARA and the second set consisted of accelerometer CMG-5T (http://www.guralp.com/documents/MAN-050-0001.pdf) and data acquisition module Platinum CMG-DAS-06 (http://www.guralp.com/documents/MAN-EAM-0003.pdf) by Guralp. The two sets of equipment were used to monitor trembling originated by quarry explosions during three months period. A few dozens of quarry explosions have been recorded. Data recorded by SARA SL07 device was processed using SEISAN 9.1.1 software while data recorded by Guralp Platinum CMG-DAS-06 device was processed using software SCREAM! 4.5 (http://www.guralp.com/documents/MAN-SWA-0001.pdf) produced by Guralp company. Measurement results from two different sets of devices coincided within limits of uncertainties. Therefore, one was firmly convinced that both sets of equipment were registering and measuring soil vibrations accurately and credibly enough.

Results of measurements

The main goal of measurements was to evaluate magnitudes of soil trembling at two steadings with dwellings due to quarry explosions and compare measured values against the norms provided in standard DIN 4150 part 3. The soil trembling characteristics were measured at two points N1 and N2 located at two steadings (table 3). Two quarry explosions were executed at existing Tūrkalne lode on 19-th of June 2013, explosion site was real property "Daces", cadastre No. 80840170011, Ropaži Municipality (table 2). All measurement results are provided in the table 4. Maximum velocities of soil trembling were measured at three frequency bands: 1-10 Hz, 10-50 Hz, 50-100 Hz and at all frequencies (1-100 Hz) according to requirements of standard DIN 4150. Firstly maximum velocity of trembling was measured at each component (Z, N, E) separately. Later maximum trembling velocity was calculated combining values of each component. This kind of calculation overestimated maximum velocities of trembling as maximum trembling velocities of each component appeared at different times and were not values of one single oscillation. Nevertheless, these overestimated values were significantly lower than maximum allowed trembling velocities defined by standard DIN 4150 and measured velocities of trembling varied from 0.06% to 2.81% of maximum allowed values (table 4).

Figures 7, 8, 9 and 10 present seismograms or time histories of trembling velocities at measurement points N1 and N2 from explosion 1 and explosion 2. Seismograms of each measurement are provided by three orthogonal components: vertical (Z), north-south (N) and east-west (E). Seismograms were filtered using filter 1-100 Hz. Values of maximum trembling velocities are provided at right side above seismogram of each component. Units of velocities are nanometers per second.

Figure 6 presents results of measured trembling velocities graphically. Naturally, one can notice that measured values of trembling velocities at site N1 were somehow higher comparing to measurements at site N2 which was farther away from explosion sites by a few hundred meters.

Table 4. Results of measurements of maximum velocities of vibrations originated by two quarry explosions.

Explo-sion, No.	**Time, hh.mm**	**Point of measu-rement**	**Frequen-cy, Hz**	**Max. measured velocity of vibration, mm/s**			**Max. velocity, mm/s**	**Max. allowed accor-ding DIN 4150, mm/s**	**Percents form max. allowed, %**
				Z	**N**	**E**			
1	16:06	1	1-10	0.040	0.065	0.040	0.086	5	**1.72**
1	16:06	1	10-50	0.019	0.019	0.038	0.047	5-15	**0.31**
1	16:06	1	50-100	0.007	0.005	0.008	0.012	15-20	**0.06**
1	16:06	1	**1-100**	**0.072**	**0.120**	**0.106**	**0.176**	**15**	**1.17**
1	16:06	2	1-10	0.056	0.094	0.060	0.125	5	**2.50**
1	16:06	2	10-50	0.027	0.035	0.063	0.077	5-15	**0.51**
1	16:06	2	50-100	0.005	0.004	0.009	0.011	15-20	**0.06**
1	16:06	2	**1-100**	**0.039**	**0.070**	**0.040**	**0.090**	**15**	**0.60**
2	16:19	1	1-10	0.036	0.074	0.039	0.091	5	**1.82**
2	16:19	1	10-50	0.065	0.066	0.121	0.152	5-15	**1.02**
2	16:19	1	50-100	0.020	0.015	0.032	0.041	15-20	**0.20**
2	16:19	1	**1-100**	**0.098**	**0.150**	**0.172**	**0.248**	**15**	**1.66**
2	16:19	2	1-10	0.060	0.105	0.072	0.141	5	**2.81**
2	16:19	2	10-50	0.090	0.102	0.149	0.202	5-15	**1.35**
2	16:19	2	50-100	0.028	0.027	0.044	0.059	15-20	**0.29**
2	16:19	2	**1-100**	**0.056**	**0.089**	**0.072**	**0.127**	**15**	**0.85**

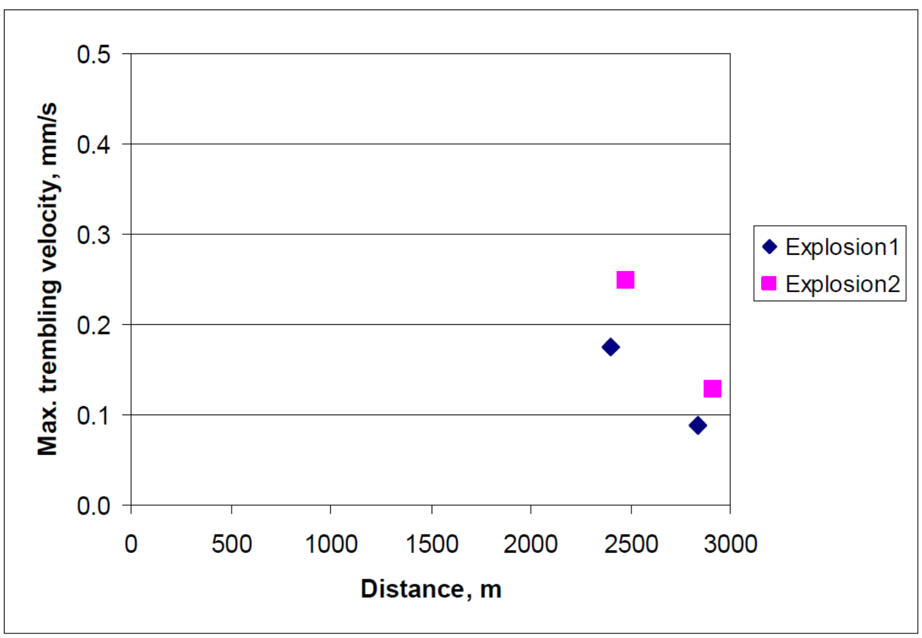


Figure 6. Results of soil trembling measurements at point N1 (distance to explosion site 1 - 2.403 km and distance to explosion site 2 - 2.478 km) and at point N2 (distance to explosion site 1 - 2.839 km and distance to explosion site 2 - 2.915 km)

Figure 7. Seismogram of explosion 1 recoded at point N1. Date: 2013.06.19. Local time: 16:06

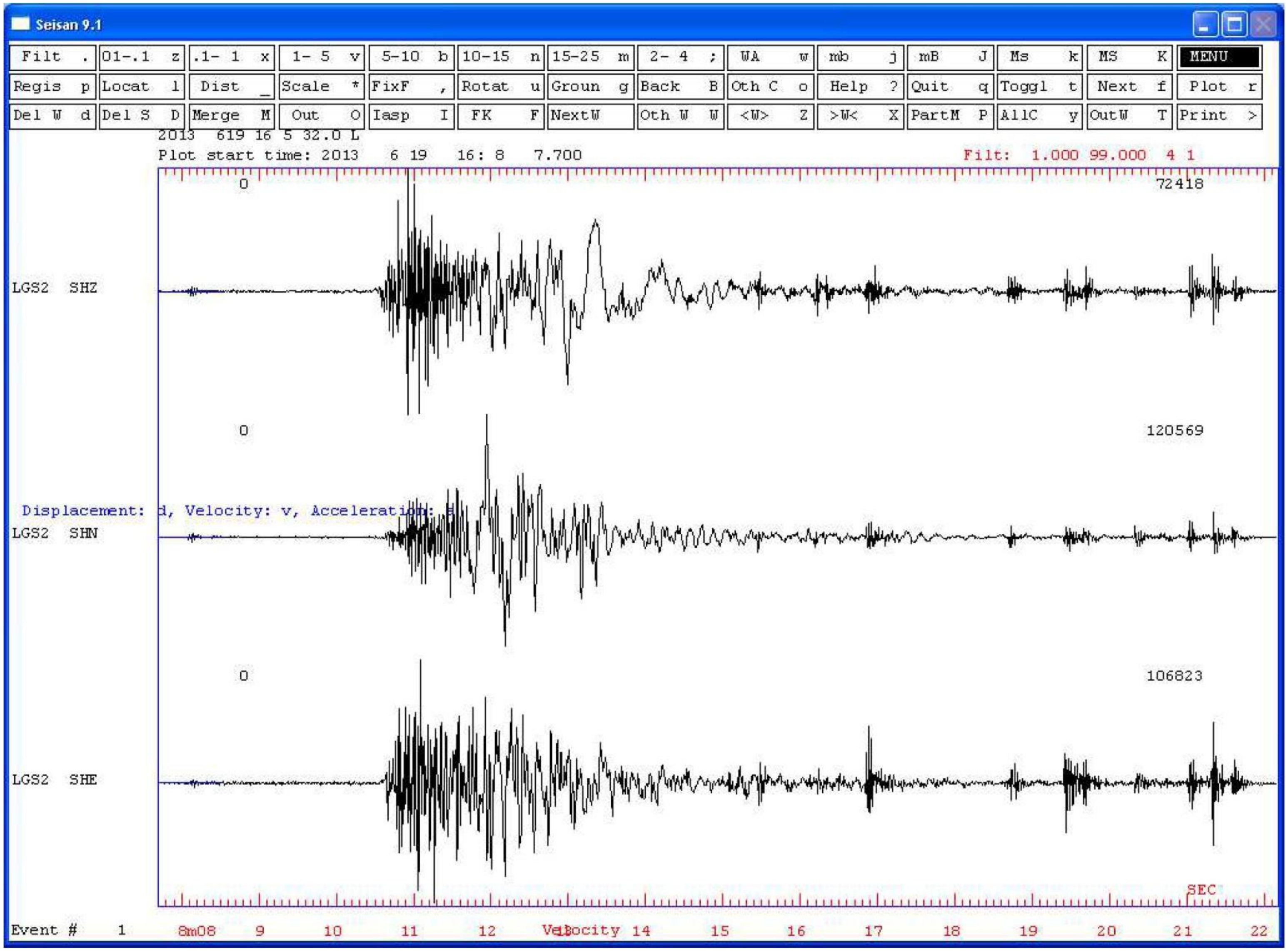


Figure 8. Seismogram of explosion 2 recoded at point N1. Date: 2013.06.19. Local time: 16:19

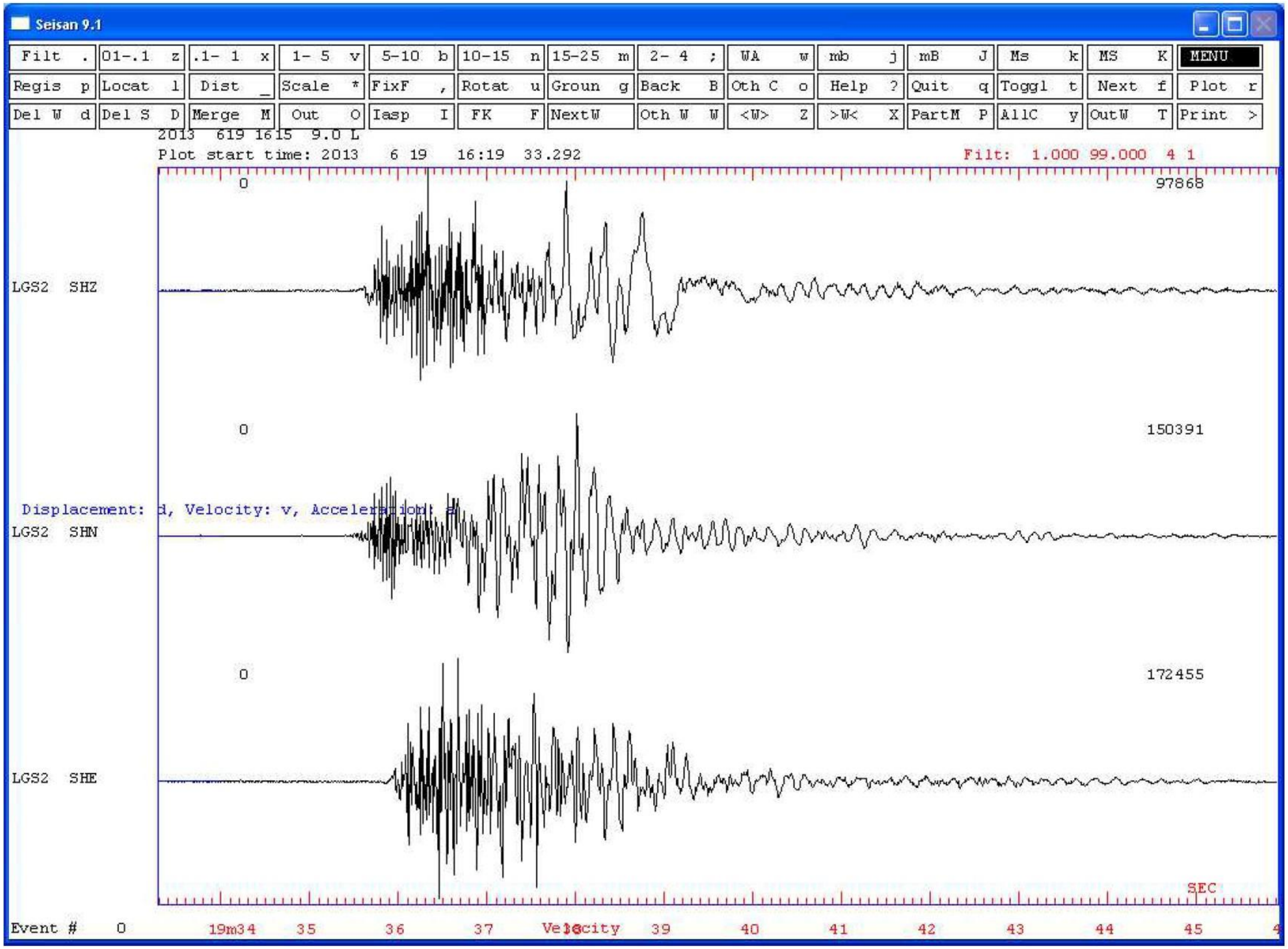


Figure 9. Seismogram of explosion 1 recoded at point N2. Date: 2013.06.19. Local time: 16:06

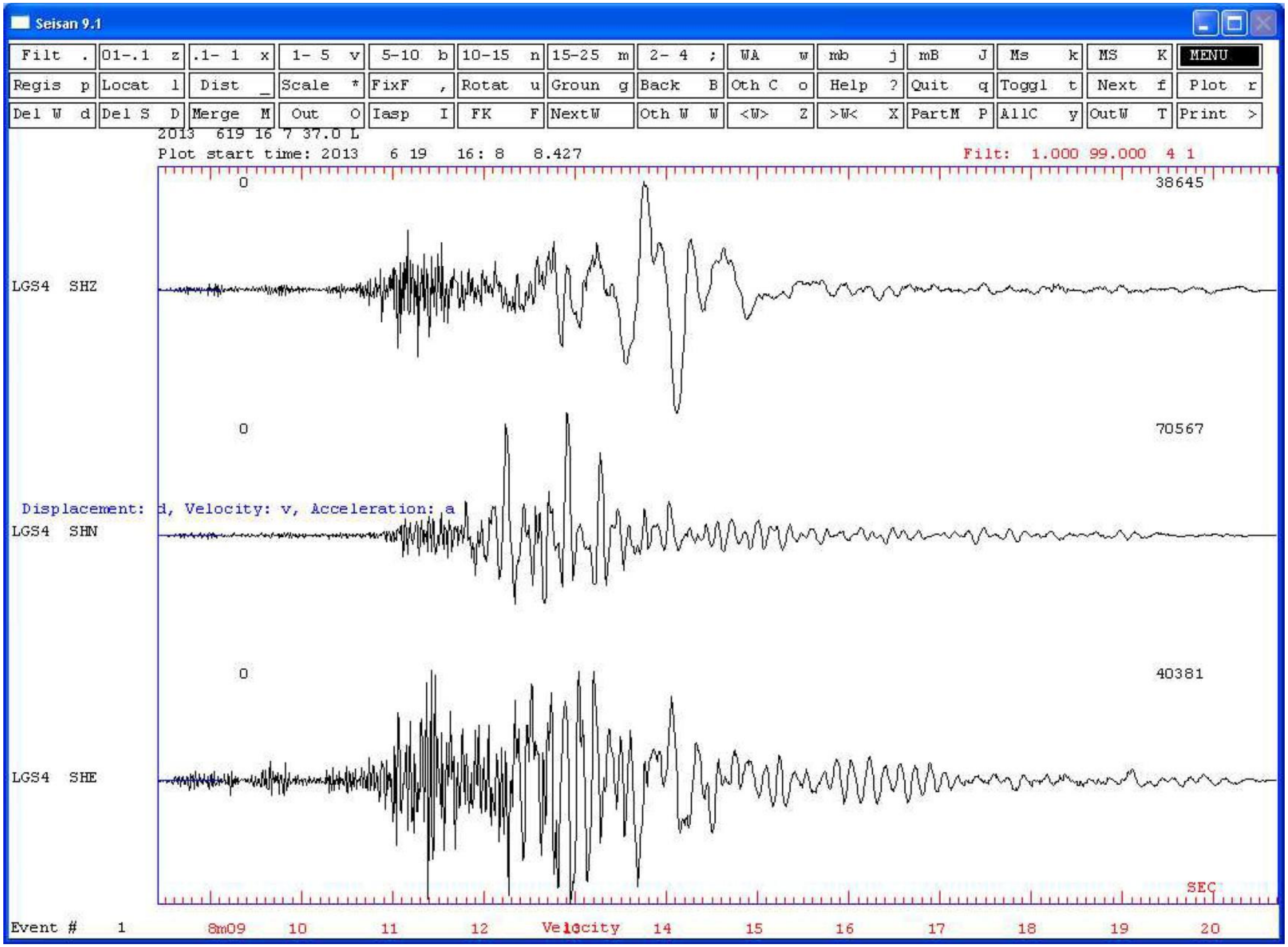
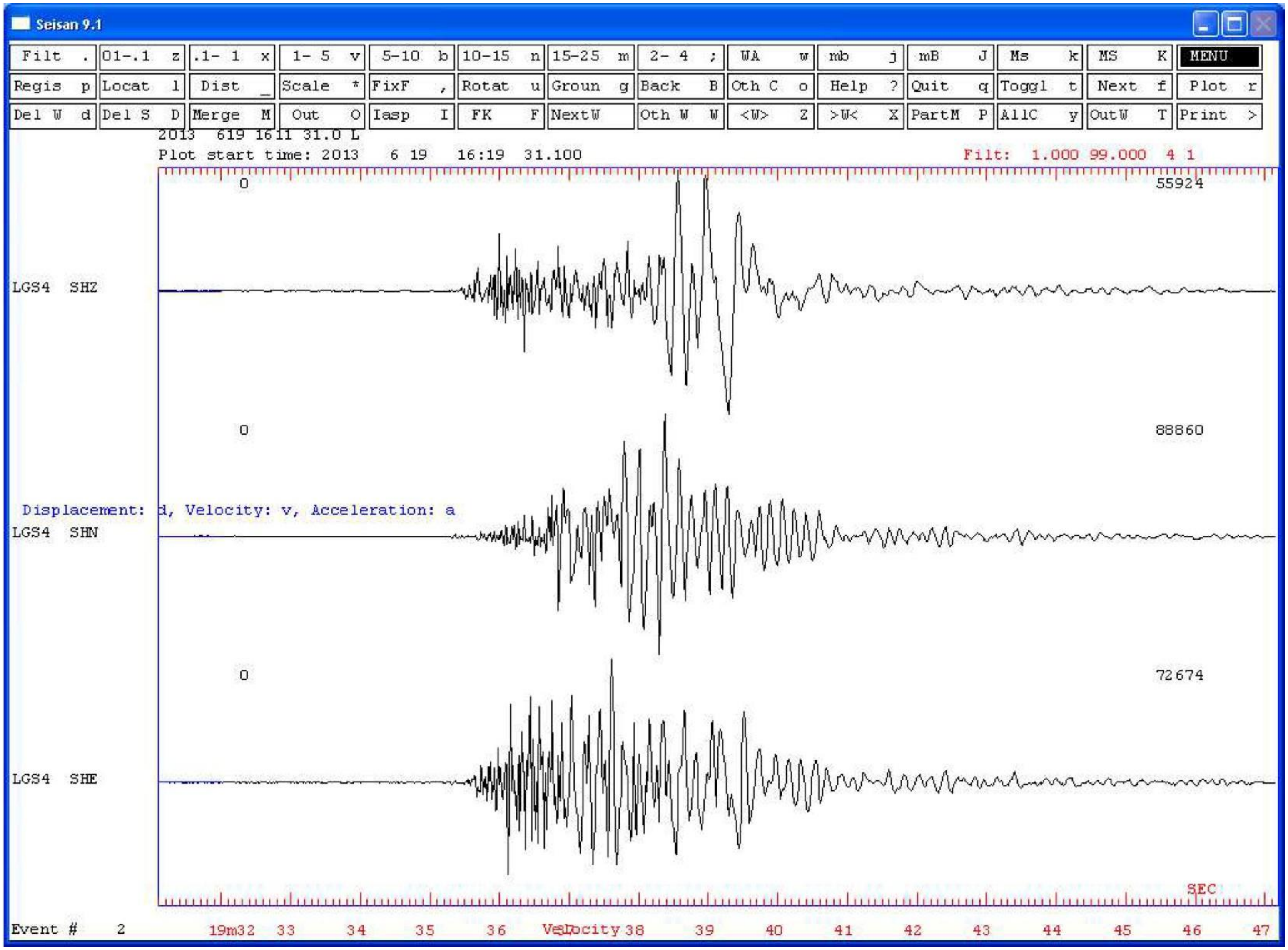


Figure 10. Seismogram of explosion 2 recoded at point N2. Date: 2013.06.19. Local time: 16:19



Prediction of vibrations of quarry explosions

A research of impact of vibrations from explosions originated at gypsum quarry Salaspils to experiment nuclear reactor was carried out in year 2002. Customer of this research (Salaspils Report) was “Knauf Marketing Riga SIA” (Daugavas Str. 4, Stopinu pagasts, LV-2132 Saurieši) and contractor of the research was “Orica Germanz GmbH” (Sprengmittelvertrieb Sachsen, Pulvermuhlenweg, 09599 Freiberg). Five experimental explosions were performed to investigate velocities of the trembling in vicinities of the quarry and at the site of experimental nuclear reactor. It was shown that none of explosions indicated trembling that exceeded maximum allowed norms according to standard DIN 4150. One chapter of report of this Salaspils Report was dedicated to predict vibrations of future explosions. Three prediction equations of soil trembling velocities were investigated. The first equation was provided in standard DIN 4150. This equation defined maximum velocities of trembling depending on mass of explosions and distance to measurement point. However this equation did not define three necessary constants. The constants had to be defined in experimental way. The second equation was called model “Ludeling – Bundesanstalt fur Geowissenschaften u. Rohstoffe”. This second equation was designed for hard rock sites and was not appropriate for soft sedimentary soil i.e. for Latvian geological conditions. The third equation was called model “Geophysik GGD fur Sprengungen im Festgestein”. This equation was designed for soil of soft sediments and corresponded to geological conditions of Latvia in best way. Moreover, Salaspils Report proved that the third equation showed best results then it was compared with five experimental explosions in Salaspils quarry. Therefore the model “Geophysik GGD fur Sprengungen im Festgestein” was adopted in this research to predict future trembling velocities originated from future quarry explosions. The equations of the model “Geophysik GGD fur Sprengungen im Festgestein” had form:

$$V_T = 16 \cdot \frac{\sqrt{0.01 \cdot L}}{(0.01 \cdot r)^{1.4786 + 0.1314 \lg(0.01 \cdot r)}},$$

$$V_{T\max} = k_1 \cdot V_T \cdot s_V$$

$$V_{T\max} = k_1 \cdot \frac{V_T}{s_V}$$

Where V_T – theoretical (predicted) trembling velocity, V_{Tmax} – maximal theoretical trembling velocity, V_{Tmin} – minimal theoretical trembling velocity, L – mass of charge in kg, r – distance between explosion and measurement point in meters, k_1 – factor of environment conditions, k_1=1 for moderate conditions, s_v – safety margin, s_v=1.8.

Figure 11 and 12 show predicted values of velocities V_{Tmax} and V_{Tmin} versus distance from explosion point for two explosions at Kalnagraviši lode which had charges of 870 kg and 3210 kg according to the model “Geophysik GGD fur Sprengungen im Festgestein”. Figure 11 shows the measured value at point N1 was between V_{Tmin} and V_{Tmax} and at point N2 was slightly higher than V_{Tmin}. Figure 12 shows the measured value at point N1 was between V_{Tmin} and V_{Tmax} and value at point N2 was almost equal to V_{Tmin}. The figures 11 and 12 show quite good agreement between measured values and calculated ones and prove that the model “Geophysik GGD fur Sprengungen im Festgestein” is appropriate one to predict velocities of trembling at vicinities of Tūrkalne quarry.

Figure 13 shows that minimal distances from closest part of new lode Areni to points N1 and N2 are 1500 and 1700 m correspondingly and from closest part of new lode Kalnagraviši to points N1 and N2 are 1700 and 2100 m correspondingly. Explosion with charge 3210 kg executed at closest part of lode Areni would produce maximal trembling of 1.73 mm/s and 1.38 mm/s at points N1 and N2. The explosion of the same charge executed at closest part of lode Kalnagraviši would produce maximal trembling of 1.38 mm/s and 0.94 mm/s at points N1 and N2. These maximal values would make just 11.5% and 9.2% of maximum allowed trembling limits for points N1 and N2 from explosion at new Areni lode and just 9.2% and 6.3% of maximum allowed trembling limits for points N1 and N2 from explosion at new Kalnagraviši lode according to standard DIN 4150.

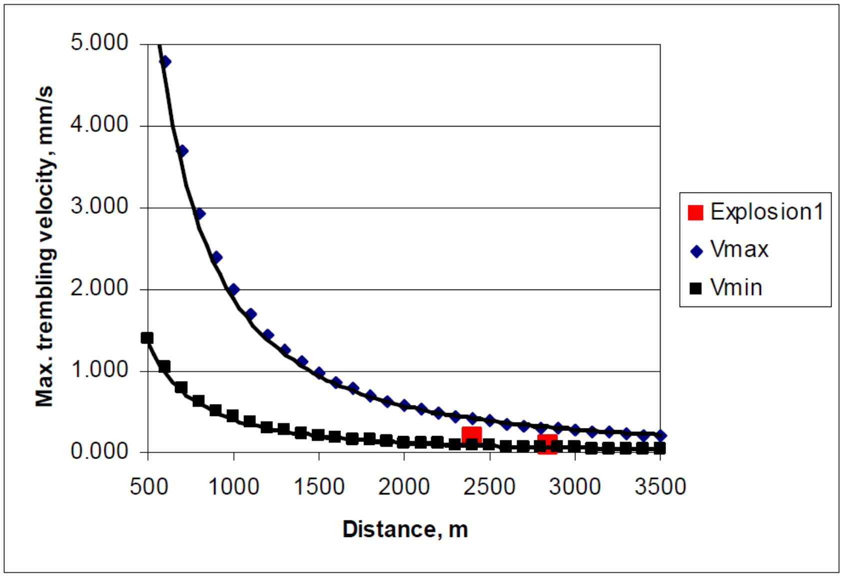


Figure 11. Predicted values V_{Tmax} (black line and blue diamonds) and V_{Tmin} (black line and black squares) versus distance from explosion point for explosion charge of 870 kg. Two red squares indicate measured values of trembling velocities of the first explosion at measuring points N1 and N2.

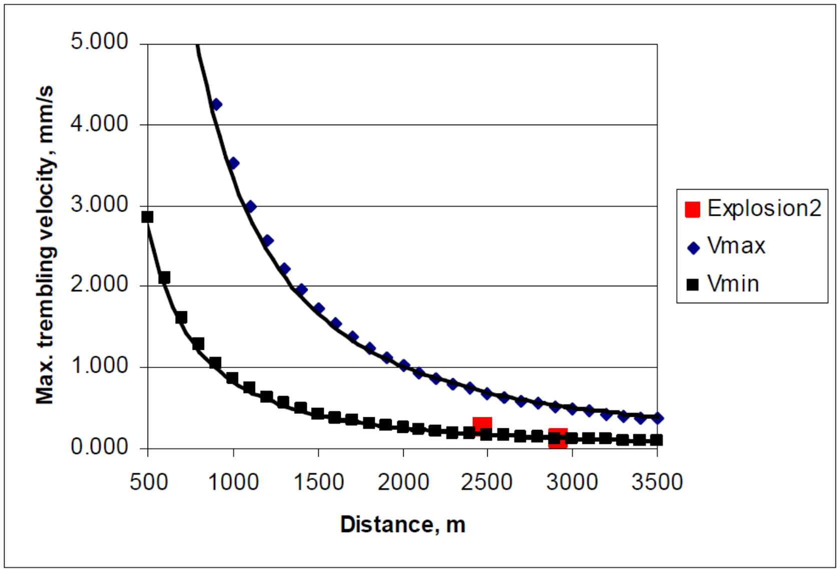


Figure 12. Predicted values V_{Tmax} (black line and blue diamonds) and V_{Tmin} (black line and black squares) versus distance from explosion point for explosion charge of 3210 kg. Two red squares indicate measured values of trembling velocities of the second explosion at measuring points N1 and N2.

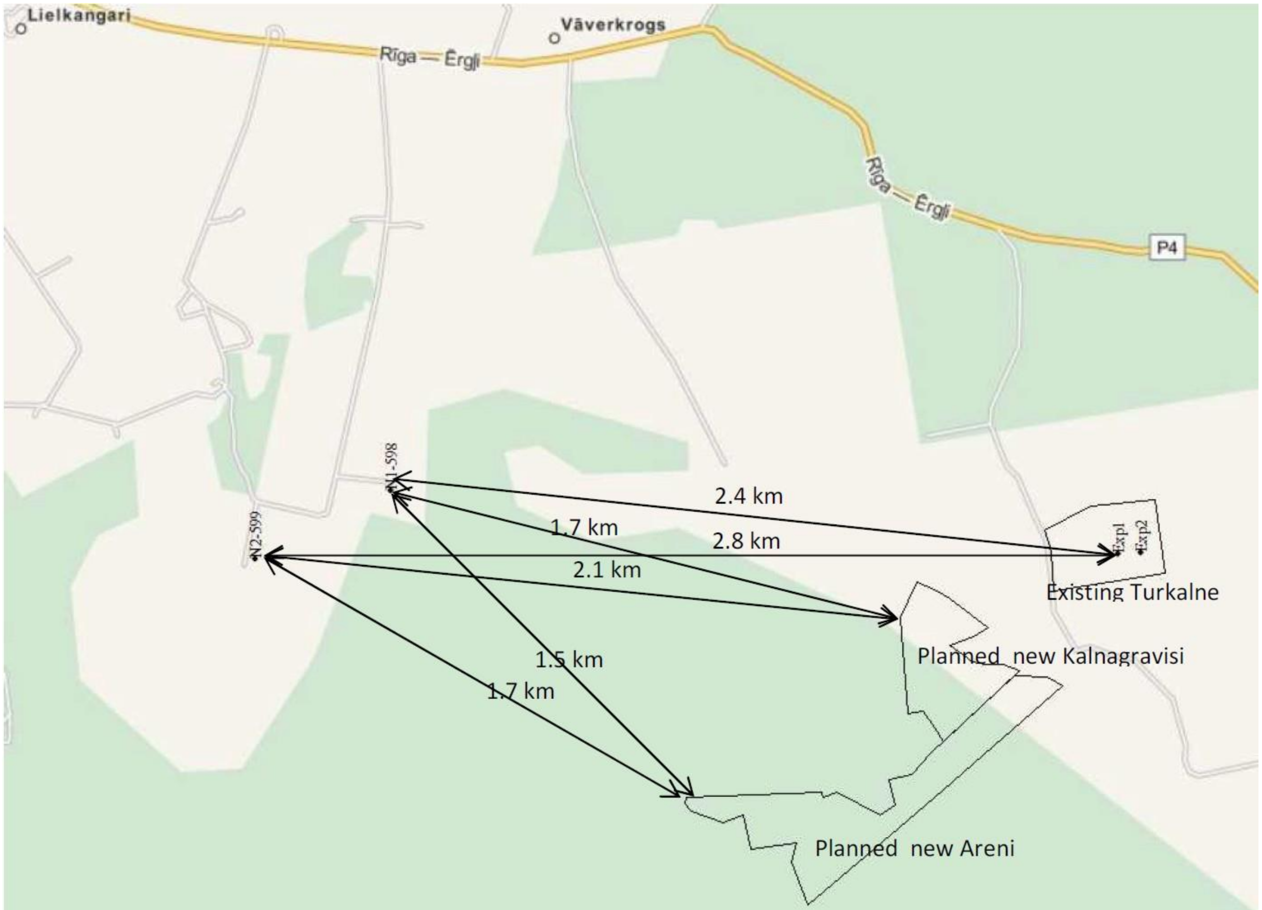


Figure 13. Map of new lodes Areni and Kalnagravіši and two nearby steadings "Paltes" (N1) and "Piparini" (N2). Ex1 and Ex2 indicate two explosions carried out at Turkalne lode on 19-th of June. Two arrows indicate distances between explosion points Ex1 and Ex2 and steadings N1 and N2. Another two arrows indicate shortest distance between steadings N1 and N2 and closest part of new Areni lode. The third pair of arrows indicates shortest distance between steadings N1 and N2 and closest part of new Kalnagravіši lode.

Conclusions

The investigation was carried out to measure trembling originated by explosions at Tūrkalne lode in Ropaži Municipality, Latvia. The measurements were performed at the two steadings N1 and N2. Two explosions were carried out at Tūrkalne lode with charges 870 kg and 3210 kg. The following conclusions can be formed using results of this investigation.

1. Maximum magnitudes of velocities of trembling spanned from 0.011 to 1.006 mm/s at measurement points N1 and N2**.** These values were significantly lower than maximum allowed trembling velocities defined by standard DIN 4150 and varied from 0.06% to 2.81% of maximum allowed values.
2. A research of impact of vibrations from explosions originated at gypsum quarry Salaspils to experiment nuclear reactor was carried out in year 2002. This research showed that model "Geophysik GGD fur Sprengungen im Festgestein" predicted magnitudes of soil trembling quite precisely. This investigation confirmed that the model "Geophysik GGD fur Sprengungen im Festgestein" predicted soil trembling in vicinities of Tūrkalne quarry precisely enough.
3. The minimal distances from closest part of new lode Areni to points N1 and N2 are 1500 and 1700 m correspondingly. The minimal distances from closest part

of new lode Kalnagraviši to points N1 and N2 are 1700 and 2100 m correspondingly. Prediction of soil trembling using model “Geophysik GGD fur Sprengungen im Festgestein” showed that explosion with charge 3210 kg executed at closest part of lode Areni would produce maximal trembling of 1.73 mm/s and 1.38 mm/s at points N1 and N2. These maximal values would make just 11.5% and 9.2% of maximum allowed trembling limits according to standard DIN 4150. An explosion of same charge executed at closest part of lode Kalnagraviši would produce maximal trembling of 1.38 mm/s and 0.94 mm/s at points N1 and N2. These maximal values would make just 9.2% and 6.3% of maximum allowed trembling limits according to standard DIN 4150.