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Seismic Impact of Massive Blasts on the Bridge and East-Slope of the Route-7: Case Study of Zhur

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Abstract: With reference to the discontent expressed by the ministry of infrastructure regarding the use of limestone at the exploitation quarry of company "Vellezerit e Bashkuar" located in Zhur Municipality of Prizren. The said complaints refer to the large seismic shakings and impact on the stability of the bridge and the eastern slope of the motorway. Therefore, we have decided to sustain seismic vibration measurements at the mentioned place. The parameters of the mining field have been included in the paperwork, along with the filling and sketches of the connection for the drilled holes. Based on the seismic measurements during the major blast, the parameters of seismic vibrations were obtained and resulted that the complaints are unfounded because the registration of seismic vibrations were maximum of 0.4 mm/s to 2.0 mm/s, whilst the allowed domain of frequency content is in the range of 6 to 10 Hz. The limit for the constructions of bridges is 5.0 mm/s, and for the slope degrees 20 mm/s. In order to achieve these reasonable results, the system with fuse was implemented for initiation of the blast field, and with this initial system we have slowed the sequences in between and slowed the drilling in the collocation. Therefore, the amount of the explosive material that detonates at the same time was significantly reduced.

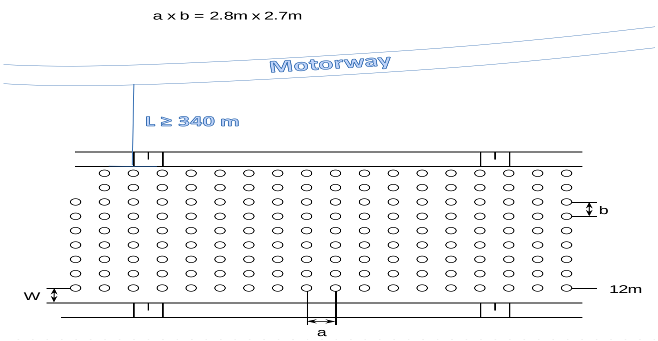
Key words: *Detonation, Initiation, Vibration, Seismic, Nonel, Motorway*

Introduction

After the 1999, requirements for the use of limestone were greatly increased in Kosovo for the purposes of real estate and road infrastructure, construction of buildings, as reducing material in the foundry and also for the regulation of PH. Due to this, a limestone explanting place was opened in Zhur - Prizren, by the company "Vellezerit e Bashkuar". The said location was opened before the construction of Kosovo Motorway started and was normally used until after the construction of the same. However, with the completion of the motorway and its release for traffic usage, complaints by the ministry of infrastructure have begun and this company was suspended from the use of limestone in the said explanting location until the confirmation of the impact effects by the massive blasts on the east-slope of the motorway and on the bridge. Thus, in order to avoid these dilemmas of the ministry of infrastructure, seismic measurements were made, which will be presented in the following paperwork.

Detonation field plan

The field in this exploitation place has 160 drillings in total with depths 12 m. The line of least resistance was W = 2.7 m, distance between rows b = 2.7 m, distance between drillings in row a = 2.8 m, drilling angle $\beta = 75^o$ and drilling diameter d = 89 mm.



Field coordinates

No.	Y	X	Z
1	7467169	4670293	533
2	7467148	4670303	531
3	7467186	4670342	530
4	7467194	4670316	535

Figure 1. Detonation field plan

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Calculation of material needed for field detonation

The calculation of the material needed for field detonation was made with MS Excel program which is provided in tabular form, where the required calculating equations were used in the Table 1.

Table 1. Detonation specifications for exploitation place in Zhur .

Quarry		**"Vëllezërit e Bashkuar"**					
Region – Municipality		**Prizren – Prizren**					
Detonating company		**"Jaha Company"**					
Date of detonation		**10.07.2015**					
		G.1	**G.2**	**G.3**	**G.4**	Total	
Total drilling length	m	480	480	480	480	1920	m'
Number of holes	N_b	40	40	40	40	160	hole
Distance between holes	a	2.8	2.8	2.8	2.8		m'
Distance between rows	b	2.7	2.7	2.7	2.7		m'
Hole diameter	Ø	89	89	89	89		mm
Drilling angle	α	75	75	75	75		^{0}
Tapping		3.5	3.5	3.5	3.5		m'
Cartridge diameter	d	89	89	89	89		mm
Cartridge length	l=cm	33.00	33.00	33.00	33.00		cm
Compression	%	5%	5%	5%	5%		%
Explosive density	γ	0.85	0.85	0.85	0.85		g/cm^3
Effective diameter of compression	d^1	91.312	91.312	91.312	91.312		mm
Effective length of compression	l^1	31.35	31.35	31.35	31.35		cm
Drilling length	L_{sh}	12	12	12	12		m'
Volume of rock per hole	V	87.613	87.613	87.613	87.613		m^3
Average rock height	H_{sh}	11.589	11.589	11.589	11.589		m'
Cartridge mass	q_s	1.744	1.744	1.744	1.744		kg
Calculated number of cartridges in hole		27.11	27.11	27.11	27.11		pcs.
Estimated number of cartridges		27	27	27	27		pcs.
Filling length		8.50	8.50	8.50	8.50		m'
Hole filling in m'		5.56	5.56	5.56	5.56		kg/m
Filling of a hole	q_{sh}	47.29	47.29	47.29	47.29		kg
Specific consumption of EXP.	q_{sp}	0.54	0.54	0.54	0.54	0.57	kg/m^3
Total filling amount with EXP.	Q_A	1891.576	1891.576	1891.576	1891.576	7566.3	kg
Measure the volume of obtained	V_A	3504.53	3504.53	3504.53	3504.53	14018.1	m^3

July, 2015

Specification of expenses for field detonation is:

AN – FO	7400 kg
EMEX (F = 50 mm)	200 kg
Nonel Detonator U475 (L = 15 m)	160 pcs.
Nonel Detonator U500 (L = 4.8 m)	160 pcs.
Nonel Connector 25 ms	18 pcs.
Nonel Connector 42 ms	142 pcs. + (2 spare pcs.)
Dynoline	300 m + (300 m reserve)

Filling and connection of field with Nonel system

After the distribution of explosive and initiation material in the field, the filling process begins. At the bottom of the drilled hole the striking cartridge together with Nonel detonator is placed (U475 ms). The filling with An – Fo begins up to the tapping level, for drillings with a depth of 12 m. In drillings with a depth of 12 m, the second initiation is also applied (as auxiliary initiation), approximately 1 m before reaching the tapping level, the second striking cartridge is placed together with Nonel detonator (U500 ms) and then filling with An – Fo continuous until tapping level is reached.

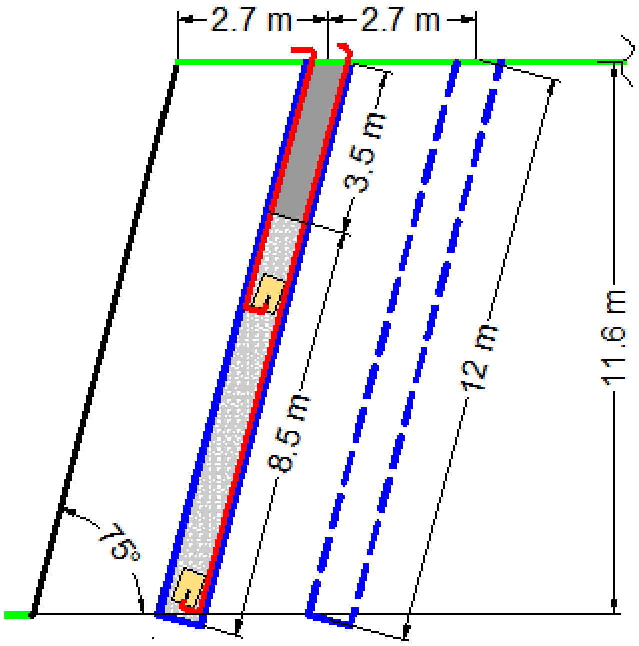


Figure 2. Schematic presentation of hole filling

Field connection with Nonel system

In order to enable the safe initiation of the connection with Nonel system we should take into account the connection of Nonel detonators that are inserted in the hole with Nonel connectors that are always on surface and should closely follow the connection from one hole to the other and from one row to the other. After all these actions are undertaken in each drill and after all connectors are placed and connected in every drill, the field is considered to be connected.

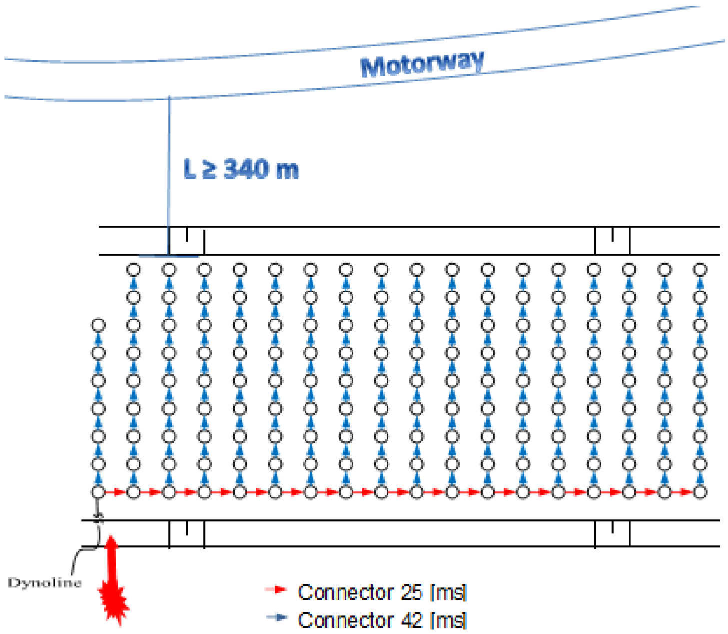


Figure 3. Schematic presentation of field connection with Nonel system

Effects of blasting and blast vibration terminology

When an explosive detonates within a borehole stress waves are generated causing much localized distortion and cracking. Outside this immediate vicinity, however, permanent deformation does not occur. Instead, the rapidly decaying stress waves cause the ground to exhibit elastic properties whereby the rock particles are returned to their original position following the passage of the stress waves. Such vibration is always generated even by the best designed and executed blasts and will radiate away from the blast site, attenuating as distance increases. There are four interrelated parameters that may be used in order to define ground vibration magnitude at any location. These are:

- Displacement: the distance that a particle moves before returning to its original position, measured in millimeters (mm).
- Velocity: the rate at which particle displacement changes, measured in millimeters per second (mms-1).
- Acceleration: the rate at which the particle velocity changes, measured in millimeters per second squared (mms-2) or in terms of acceleration due to the earth's gravity (g).
- Frequency: the number of oscillations per second that a particle undergoes measured in Hertz (Hz).

Much investigation has been undertaken, both practical and theoretical, into the damage potential of blast induced ground vibration. All have concluded that the vibration parameter best suited as a damage index is the peak particle velocity (PPV). Thus the parameters most commonly used in assessing the significance of an impulsive vibration are those of particle velocity and frequency which are related to sinusoidal motion as follows:

$$PV = 2 \cdot \pi \cdot f \cdot a$$

where
PV = particle velocity
π = pi
f = frequency
a = amplitude

It is the maximum value of particle velocity in a vibration event, termed the peak particle velocity (PPV), that is of most significance and this will usually be measured in three independent, mutually perpendicular directions at any location in order to ensure that the true peak value is captured. These directions are longitudinal (or radial), vertical and transverse. Such maximum of any measurement is the accepted standard worldwide and is recommended by the DIN 4150-3, British Standards institution and the International Standards Institute amongst others. It is also the basis for all the recognized investigations into satisfactory vibration levels with respect to damage of structures and human perception. All research and previous work undertaken has indicated that any vibration induced damage will occur immediately if the damage threshold has been exceeded and that there is no evidence of long term effects.

Site description and measuring equipment

We are were selected a two locations lying on motorway Zhur - Prizren for measuring. The first location is Slop located 350m from the explosion source, while the second one is a reinforced concrete bridge. From visual inspection, it is concluded that the soil of the whole area is of hard soil type. The slope was constructed with three steps and is separated from the motorway by 10m wide service road. At this location, two measuring points were placed. The first one 'MP-1' was located at the last (top) stage, while the second 'MP-2' at the level of the service road (bottom of the slope). The bridge structure is a modern reinforced structure, which was constructed according to the modern principles. It consists of RC columns, main girders and plate. At this location one measuring point was placed 'MP-3'. It was located at the level of the foundation. The location of the source of the explosion and three measuring points is graphically presented in Figure 4. The site of the third measuring point (MP-3) is shown in Figure 5.

Figure 4. Measuring points and source of explosion

Figure 5. View of the third measuring point (MP-3)

The equipment included three 16-bit recorders SSR-1, with serial numbers 272, 232 and 227, as well as nine short-periodic electromagnetic seismometers SS-1. At the three channels of each of the recorders on each individual location, the seismometers were connected as follows: one seismometer to record the velocities of ground displacements in vertical direction, another to record the velocities of the horizontal ground displacements in the direction from the location to the quarry, and the third to record the velocities of horizontal ground displacements in the direction normal to the direction of the location toward the quarry. In all three SSR-1 recorders, the parameters that can be selected were selected equal for the purpose of comparability of the obtained records. All the most important parameters of these recorders are given in the subsequent Table 2.

Table 2. Basic Parameters for all three SSR-1 digitalizes.

SSR-1 with serial numbers of 272, 232 and 227			
– *Recorder resistance* R_{SSR-1} (Ω)	100000	100000	100000
– *Recording voltage range,* V_R = 5 V (+ / - 2.5 V)	5	5	5
– *AD-converter dynamic range in digital counts,* $D_{ADC} = 2^{16} = 65536$ Counts	65536	65536	65536
– *AD-converter pre-amplifier gain,* $G_{preamp.}$	1	1	1
– *Recording media gain in Counts/V ,* $G_{SSR-1} = \frac{DADC}{V_R} \cdot G_{preamp.}$	13107.2	13107.2	13107.2
– *Low-pass filter: type, corner frequency, number of poles of the complex transfer function*	Butterworth 250 Hz 6	Butterworth 250 Hz 6	Butterworth 250 Hz 6
– *High-pass filter: corner frequency, number of poles of the complex transfer function*	0.01 Hz 2	0.01 Hz 2	0.01 Hz 2
– *Rate of sampling* (ms)	5	5	5

Damage criteria

Numerous measurements of vibration velocity in building foundations have provided empirical values which give guidance in the evaluation of short-term structural vibration. In this assessment, DIN 4150-3 standard is used to evaluate the effects of short and long term vibration on structures. Evaluations as in this standard are based on the maximum absolute value of the velocity signals, for the three components. Table 3. and Table 4. give guideline values for velocity at the foundation and in the plane of the highest floor of various types of buildings due to short and long term effects. Experience has shown that if these values are complied with, damage that reduces the serviceability of the building will not occur. If damage nevertheless occurs, it is to be assumed that other causes are responsible.

Table 3. Guideline values for vibration velocity to be used when evaluation the effects of short-term vibration on structures

Line	Type of structure	Guideline value for velocity (u_i), in mm/s			
		Vibration at the foundation at a frequency of			Vibration at horizontal plane of highest floor at all frequencies
		1 Hz to 10 Hz	10 Hz to 50 Hz	50 Hz to 100 Hz*	
1	Buildings used for commercial purposes, industrial buildings and buildings of similar design	20	20 to 40	40 to 50	40
2	Dwellings and buildings of similar design and/or occupancy	5	5 to 15	15 to 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 to 8	8 to 10	8

* At frequencies above 100 Hz, the values given in this column may be used as minimum values.

Table 4. Guideline values for vibration velocity to be used when evaluation the effects of long-term vibration on structures

Line	Type of structure	Guideline values for velocity, (u_i), in mm/s, of vibration in horizontal plane of highest floor, at all frequencies
1	Buildings used for commercial purposes, industrial buildings, and buildings of similar design	10
2	Dwellings and buildings of similar design and/or occupancy	5
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)	2.5

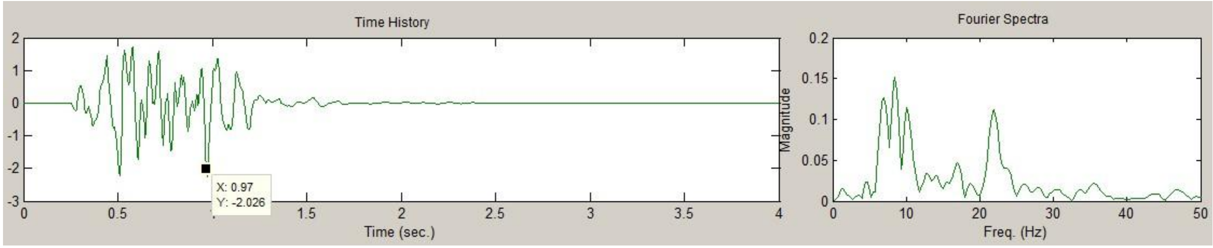
In literature, there are many damage criteria that describe the relationship between PPV and damage level. In this assessment, the damage criteria proposed by Kutuzov are used to evaluate the damage level of hard soil media (Table 5).

Table 5. Damage to hard rock massifs by blasting depending on the velocity of seismic vibrations PPV (Kutuzov et al., 1988)

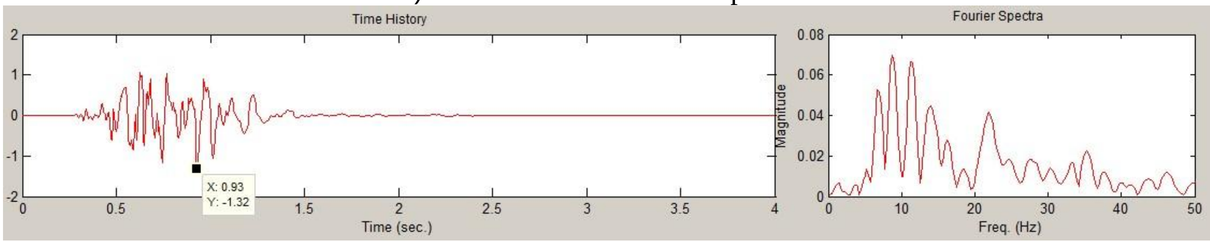
PPV (mm/s)	Damage to land due to seismic vibration
< 20	With no effect upon the surrounding lithomedia - "purely elastic transfer" of seismic vibrations into the surrounding lithomedia.
20 – 50	Negligible development of existing cracks in the surrounding lithomedia, falling of previously disintegrated pieces of rocks.
50 - 100	Intensive development of existing cracks and faults in the surrounding lithomedia with falling of pieces of rock with proportions of up to 0.2 x 0.2 x 0.2 m, opening of cracks and failures along previously destabilized slopes.
100 - 150	Widening of existing cracks, falling of pieces with proportions of up to 0.5 x 0.5 x 0.5 m over loosened surfaces
150 - 300	Falling of pieces of the roof and the sides of the underground premises over loosened surfaces, formation of cracks in the undamaged rock massif, separation of background supporting columns from rocks, failures along storey slopes.
300 - 400	Failures in the roofs and sides of underground premises and filling of up to 1/2 of the cross-section of the premises, falling of blocks with proportions of up to 1.0 x 1.0 x 1.0 m, failures of slopes on the hardest rocks.
> 400	Total destruction of the continuity of the massif with filling of over 1/2 of the initial cross-section of the underground premises, falling of blocks with proportions exceeding 1.0 x 1.0 x 1.0 m.

Results of seismic measuring

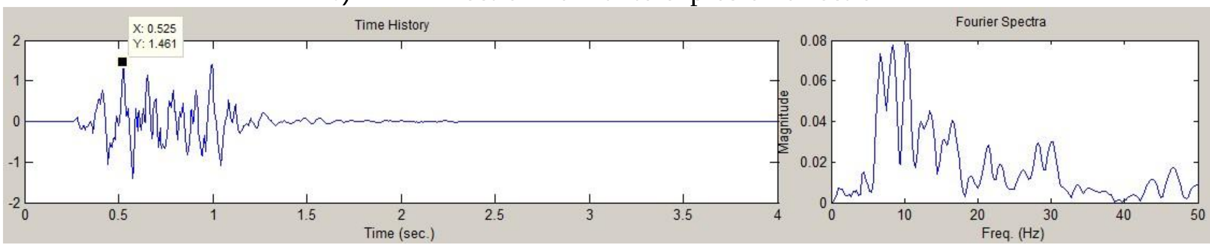
The vibration effect on the structures was measured at three measuring points (MP-1, MP-2 and MP-3) which are shown in Figure 4. The vibration was measured by velocimetry (Rangers type: Kinemetrics SSR-1) in units of mm/s. The recorded time histories of soil motion and their frequency content are shown in Figure 6, 7 and 8. The measured velocity and resonant frequency range are extracted from the recorded data and are presented in Table 6. From the obtained results, it can be concluded that the ground velocity in all locations is in the range from 0.4 to 2.0 mm/s, while the dominant frequency content is in the range of 6 to 10 Hz.



a) Direction toward explosion

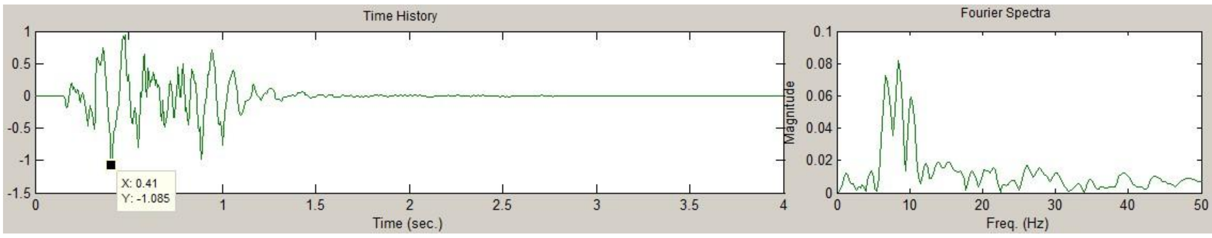


b) Direction normal to explosion direction

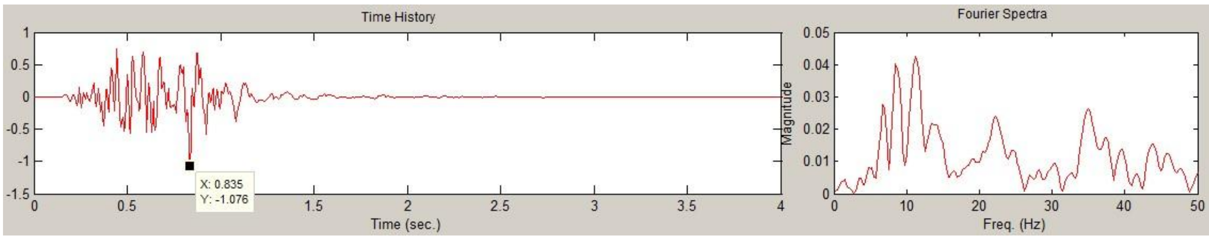


c) Vertical direction

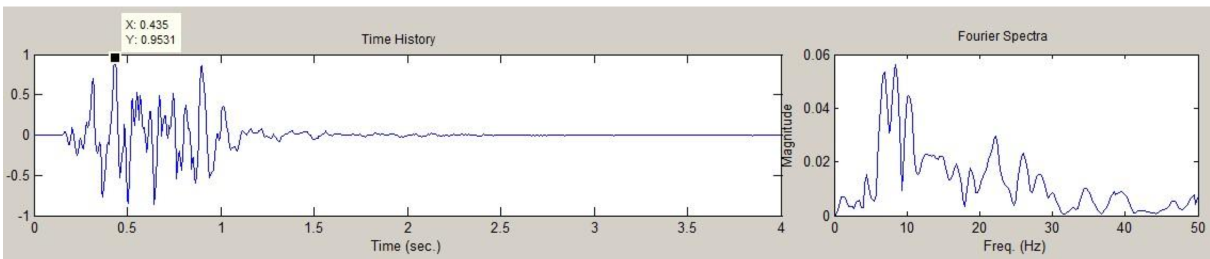
Figure 6. Time history of velocity [mm/s] and Fourier spectra of vibration at MP-1



a) Direction toward explosion

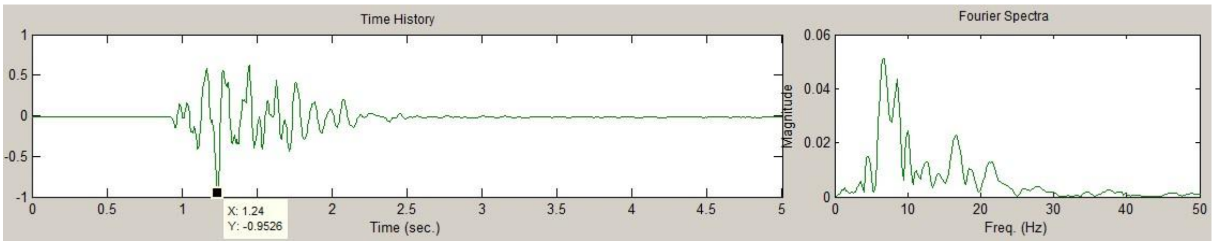


b) Direction normal to explosion direction

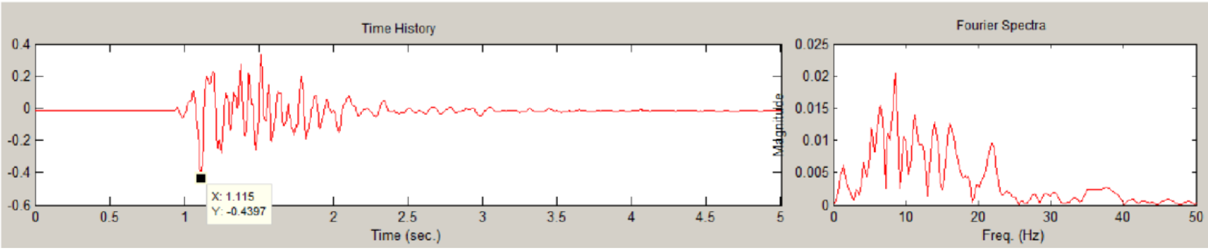


c) Vertical direction

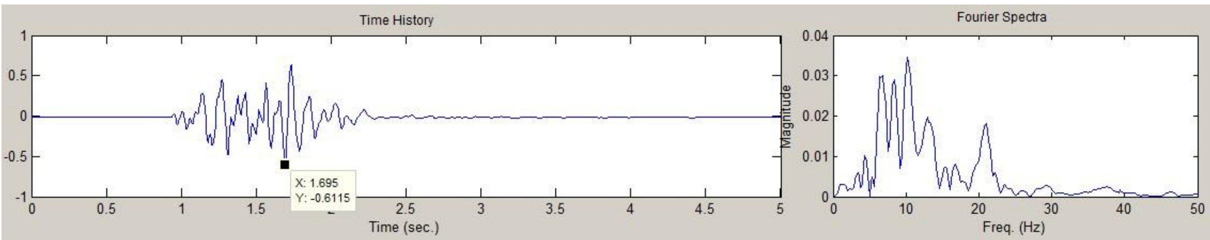
Figure 7. Time history of velocity [mm/s] and Fourier spectra of vibration at MP-2



a) Direction toward explosion



b) Direction normal to explosion direction



c) Vertical direction

Figure 8. Time history of velocity [mm/s] and Fourier spectra of vibration at MP-3

Table 6. Peak velocity and resonant frequency

Measuring Point	Direction	Peak velocity [mm/s]	Frequency [Hz]
	toward explosion	2.02	6÷10
MP-1	normal to explosion	1.32	6÷12
	vertical	1.46	6÷11
	toward explosion	1.08	6÷10
MP-2	normal to explosion	1.07	6÷12
	vertical	0.95	6÷11
	toward explosion	0.95	6÷8
MP-3	normal to explosion	0.44	6÷8
	vertical	0.61	6÷11

Conclusion

The aim of the testing was to perform an assessment of blasting vibration impact on the bridge structure and the slope near the motorway at Zhur, Kosovo. Therefore, a trial blasting took place on 10th of July, 2015. Three measuring points were defined in order to obtain the peak particle velocity for both structures (Slope and Bridge). Relevant guidance and standards have been consulted to arrive at suitable vibration criteria to preclude damage occurring at the nearest structures outside the boundary of the site. The measured values were compared to allow one defined in DIN 4150-3 for bridge structure and recommended one by Kutuzov for hard soil media. In general, a velocity level of 5 mm/s is considered appropriate for vibration effects on the bridge structure. Also, a velocity level of 20 mm/s is considered appropriate for the slope location. The obtained results from monitoring of the vibration effects on structures showed that the trial explosion induced ground velocity of range 0.4 to 2.0 mm/s which are lower than the recommended defined in the standards. Therefore, there are no expected short-term and long-term damages on structures due to the defined blasting vibrations.

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