Southeastern Europe Tunnelling Conference (SETC-2025)
1-3 October 2025, Belgrade, Serbia

DOI: 10.5937/SETC25030D

Assessment of vibrations induced by the blast during mining operations in the tunnel "Iriški Venac"

Dejan Dragojević[a], Željko Zugić[b], Milan Uljarević[c]*

[a] SK Engineering, Serbia; dragojevic.dejan@yahoo.com
[b] Power Construction Corporation of China Limited, Ogranak Beograd; zeljko.zugic@powerchina-intl.eu
[c] CRBC Serbia, Novi Sad, Serbia; umilan89@gmail.com

Abstract: This paper presents results of the vibration measurements on the surface of the terrain above the tunnel "Iriški Venac" induced by the blast during mining operations in the tunnel. The vibrations were measured on the terrain surface approximately 180m above the tunnel blast spots in the immediate vicinity of the small settlement. The main goal of the study was to estimate possible impact of vibrations on the structures of existing buildings and to provide material evidence of true levels of amplitudes of vibrations in case of possible legal dispute. Maximum measured peak particle velocities were 1mm/s and 1.25mm/s. The estimation of vibration on structures was performed according to standard DIN 4150-3, by the comparison of measured velocities with threshold values in the standard. The key findings are that the measured velocities were well below the threshold values that could cause any harm to existing buildings.

Keywords: vibration measurement; tunnel; blasting impact; ground vibration; vibration standards

1. Introduction

Vibrations that cause harm to buildings are mechanical oscillations of solid bodies that have the potential to cause discomfort to persons or damage to structures. The purpose of vibration measurements during the mining operations that include explosions in the process of breaking of solid rock can be, among others, to estimate possible impact of induced vibrations on existing buildings, or that could cause discomfort to occupants.

The effects of ground vibrations include damage to buildings structure, such as fatigue damage like cracking and breakage, damage to buildings contents, disturbance to human comfort, and audible effects such as structure-borne noise and secondary rattling of building elements or contents.

Several studies have addressed this problem, for instance (K.M. Norén-Cosgriff et al., 2020) focuses on effects of test blast on new buildings that were constructed and monitored for the purpose of study. Test blasts were designed to produce increasing vibration values, starting with peak particle velocities (PPVs) around 20 mm/s and ending with PPVs above 250 mm/s. No visible cracks were found on any of the two buildings. However, the last blast, which produced PPVs above 260 mm/s, resulted in a residual displacement of 0.05 mm across the 110 mm strain gage length above the door of the concrete building. The results of the test indicate that the limit values of most national standards include a large safety margin for buildings founded on rock.

P.K. Singh et al., 2010 addressed the effect of blast produced ground vibration on damage potential to residential structures to determine safe levels of ground vibration for the residential structures and other buildings in mining areas. For that purpose, impacts of 341 blasts detonated at two mines were monitored at the test structures and 1871 blast vibrations signatures were recorded on or near the test

*Corresponding author: dragojevic.dejan@yahoo.com

structures. The study found that at peak particle velocities of ~51.6 – 56.3 mm/s cosmetic cracks appeared.

In the study Zhang et al. 2022, focused on the effect of a blasting vibration from an excavating tunnel on an adjacent excavated tunnel. The important conclusion from this study is that the attenuation of the vibration waves caused by blast varied in different regions, and particle velocities in the region along the excavating direction were 1.12 to 1.79 times larger than in the region opposite to the excavating direction.

In the paper Zhou et al., 2024 authors dealt with comparison of overbreak and underbreak value with the traditional method to determine the degree of overbreak and underbreak. It also provided useful insights into the instrumentation for the monitoring of the blasts .

In this study, the impact of the measured vibrations on the structures was estimated according to the DIN 4150-3 standard (DIN 4150-3).

For the purpose of estimating the aforementioned effects of vibrations on buildings and occupants, the vibration measurements took place during the mining operations in the tunnel "Iriški Venac". The aim of the measurements was to estimate possible impact of induced vibrations on the existing buildings above the tunnel. The existing buildings are located somewhat 180 m directly above the tunnel and the place of blast during mining operations and consist of small settlement of one to two storey buildings. The vibrations were measured on the terrain surface i.e. - "free field" measurements took place in the immediate vicinity of existing buildings. In total two measurements were recorded when the mining operations took place approximately directly below the settlements, that were estimated to be the events that could cause largest amplitudes of vibrations on the buildings.

The significance of such measurements besides estimating the potential damage to structures and excess of certain threshold of vibrations on occupants is to acquire material evidence of vibrations in case of potential court proceedings. Thus, such measurements present cost - effective way either to prevent such cases or to obtain material evidence of true levels of amplitudes of vibrations in case of possible dispute. The results of this study showed that no negative effects on buildings should be expected.

2. Methodology

Measurements took place in the late February and early March of 2025. In total two measurements were taken on the soil surface in the immediate vicinity of buildings (Fig. 1). The surface soil layer covered with vegetation was excavated, and the instrument was placed on the natural ground below the surface vegetation layer. Both measurement locations are very close to each other so that the results of the different recordings could be comparable. The measurements took place during the favourable weather conditions without wind, rain or other meteorological impact that could increase ambient noise. Also, during the recording there were no traffic inside the settlement, and the nearest public road with low traffic is located 70m from the recording location.

Fig. 1 shows the locations of the measurement with excavated surface layer of soil. In the background of the measurement locations, the typical building types of the small settlement can be seen. It is noticeable that the buildings are predominantly consistent of ground floor buildings.

The sensor were placed on ground surface in the middle of the small settlement in order to possibly cover the most relevant ground surface vibration quantities for the whole settlement. In this particular case, the possibility of placing instrument inside the buildings was excluded due to property limitations. However, that would possibly limit the measured quantities for the particular building, since the measured signal could be affected by the building foundation system, floor coverage etc. In that case the recorded signal could even be possibly attenuated compared to the free field measurement.

Since the majority of the buildings in the settlement were ground floor buildings, no significant amplification of the recorded signal is expected due to modal response of building.

(**a**) (**b**)

Fig. 1. (a) Location of the instrument during the first measurement (b) Location of the instrument during the second measurement.

Longitudinal section of the tunnel with the measurement location marked with arrow is presented on the Fig. 2. The blast position is approximately directly below the measurement location. There is approximately 180m meters between the blast location and the measurement location.

The material surrounding the tunnel on the spot of the blast located below the measurement location consist of mechanically less damaged serpentinite, with silicified and carbonated serpentinite - listwanite. As it can be seen from the Fig. 2, this part of the material where the blast took place is the new section of the tunnel material that extends on the previous larger sections consisted of cretaceous flysch consist of claystones with interlayers of siltstones. Claystones are laminated to thin plated, with noticeable shearing marks on laminas, and easily splits. Siltstones are thin bedded, hard and compact, grey to light grey in colour. Bedded sandstones are brittle, and they are subordinately represented in rock mass with about 10% share. Flysch sediments are folded, with frequent fractures.

As it can be noticed from the Fig. 2, the material of the tunnel is non-homogenous along the length of the tunnel.

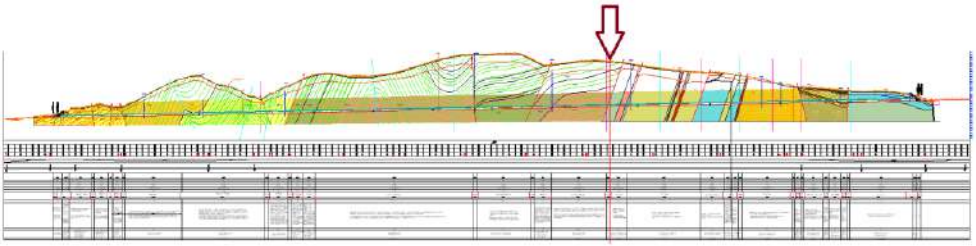


Fig. 2. Longitudinal section of the tunnel with the measurement location marked with arrow. The blast position is approximately directly below the measurement location.

Layout of the tunnel on the background satellite map is presented on the Fig. 3, together with the marked measurement location with arrow. The public road is located north and west from the measurement location.

Fig. 3. Layout of the tunnel on the background satellite map. Measurement location is marked with arrow.

The measurement included two three-component sensors for direct measurement of velocity and accelerations. The components are oriented in three orthogonal directions (NS-EW and Z) and the NS component is placed according to the magnetic north.

The measurement was performed by a new and factory calibrated sensor with low self-noise. The lowest recordable quantities are 0.00003051804 mm/s for velocity and 0.06866560000 mm/s^2 for acceleration. The maximum acceleration measurement range is ±2g. The sampling rate was set to 512 Hz.

For the measurement of velocity, two separate modes were used – both high-gain and low-gain range was used, which included the record of the lowest and highest possible measurement values, and in addition, acceleration was measured. Therefore, a record of velocity was made on six channels (three channels each for high and low gain), and three channels for measuring acceleration, which makes a total of nine channels of measured quantities.

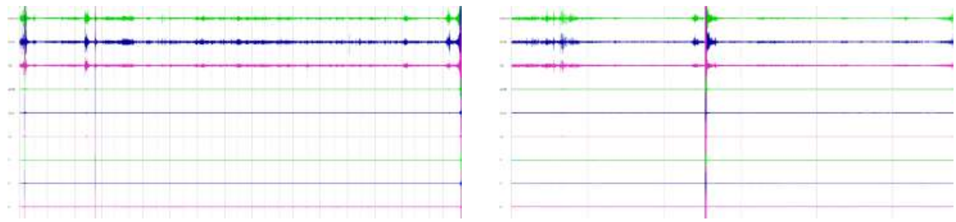
The first measurement was performed over a duration of 32 minutes and 24 seconds in order to record the ambient noise besides the event itself. The second measurement lasted 5 minutes and 48 seconds and was focused solely on the effects of the blast.

For the purpose of evaluating the effects of measured vibration on structures, the provisions of standard DIN 4150-3 were used. The DIN 4150-3 standard sets different guidelines for vibration velocities depending on the three building types and frequency ranges which are divided into three groups. The frequency ranges are divided into groups ranging from 1 Hz to 10 Hz, from 10 Hz to 50 Hz, and from 50 Hz to 100 Hz. Building are categorized into three types: type 1 - commercial and industrial, type 2 - residential and type 3 – sensitive buildings. For commercial and industrial buildings, the limits range from 20 mm/s up to 50 mm/s depending on the frequency range, while for residential buildings, the limits range from 5 mm/s up to 20 mm/s. For buildings sensitive to vibration that have great intrinsic value, the limits range from 3 mm/s up to 10 mm/s depending on the frequency range.

The standard also divides vibrations into short-term and long-term vibrations, where short-term vibrations do not occur frequently enough to cause fatigue and do not cause resonance in the assessed structures, while long-term vibrations are all vibration types that cannot be classified as short-term vibrations. Above mentioned values and thresholds correspond to the criteria in the standard that are corresponding to the short-term vibrations.

3. Results

The traces of all recorded signals are shown in the Fig 4. At the beginning and at the end of the record, noise caused by the distancing from the sensor and approaching to the sensor was observed. From the signal trace itself it can noticed that the amplitudes of motions caused by the blast are approximately on the level of the noise of human steps of approaching the instrument and distancing from the instrument. Distancing from the instrument during the recording of the blast event is estimated to be minimum 30 meters to minimize any possible impact of human noise on the recordings. The blast recording itself can be seen on the signal trace, as well as the fact that at the moment of the explosion there were no artificially induced vibrations nearby the instrument that could compromise the recording.



(a) **(b)**

Fig. 4. (a) Signal trace of the first measurement (b) Signal trace of the second measurement.

Maximum observed measured quantities are presented in the Table 1.

Table 1. Maximum observed measured quantities.

Measurement No	Component	Max. velocity [mm/s]	Max. acceleration [mg]
1	NS	1.03	-45.66
	EW	1.25	-71.82
	Z	0.74	40.71
2	NS	-1.01	26.99
	EW	-1.03	39.21
	Z	0.78	28.98

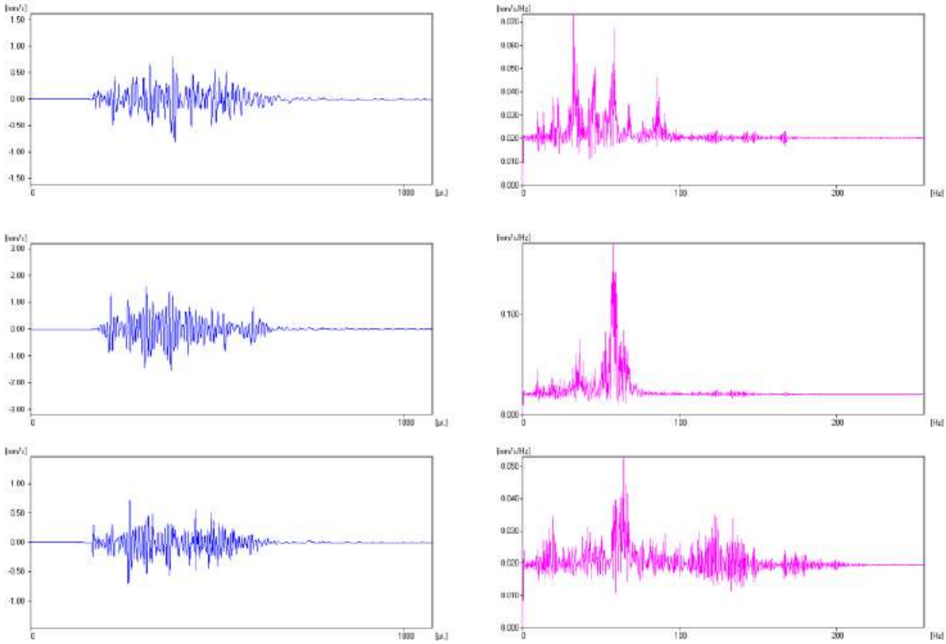
In both measurements maximum values of recorded velocity is approximately 1 mm/s with 1.25 mm/s in first measurement as the largest value on the EW component. On this component the maximum acceleration of 71.8 mg is recorded which is the largest value among all recorded accelerations.

For the first measurement, the part of the signal traces with the blast are shown on the Fig. 5 (a) together with the accompanying spectral diagrams (b).

The frequency content of the signal on horizontal components is majority in the range of frequencies between 20 Hz and 90 Hz. Z component has some spectral accelerations above 100 Hz, while on the horizontal components these spectral accelerations are negligible.

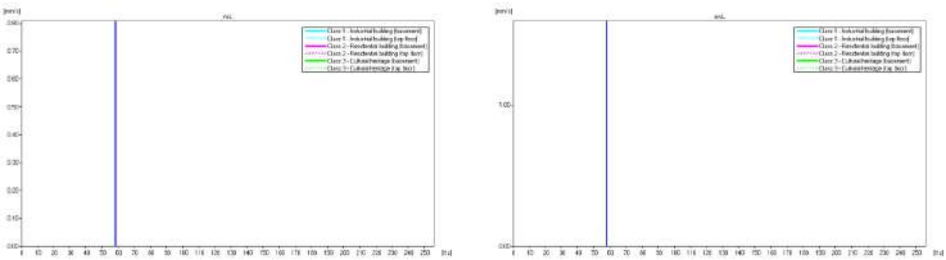
EW and Z component have distinguished one peak around 60 Hz, while the NS component has broader zone of spectral amplifications ranging from 20 Hz to 90 Hz.

For the purpose of evaluating the velocity values according to the DIN 4150-3 standard, the threshold of 1mm /s is set having in mind the largest recorded values, in order to separate epochs in which these vibration levels exist, together with the accompanying frequency content. The results are presented on the Fig. 6 for the NS component (a), and EW component (b).



(**a**) (**b**)

Fig. 5. (a) Traces of the part of the signal with the blast of the first measurement with NS, EW and Z component going from top to the bottom of the figure (b) Corresponding spectral diagrams of the NS, EW and Z component going from top to the bottom of the figure.

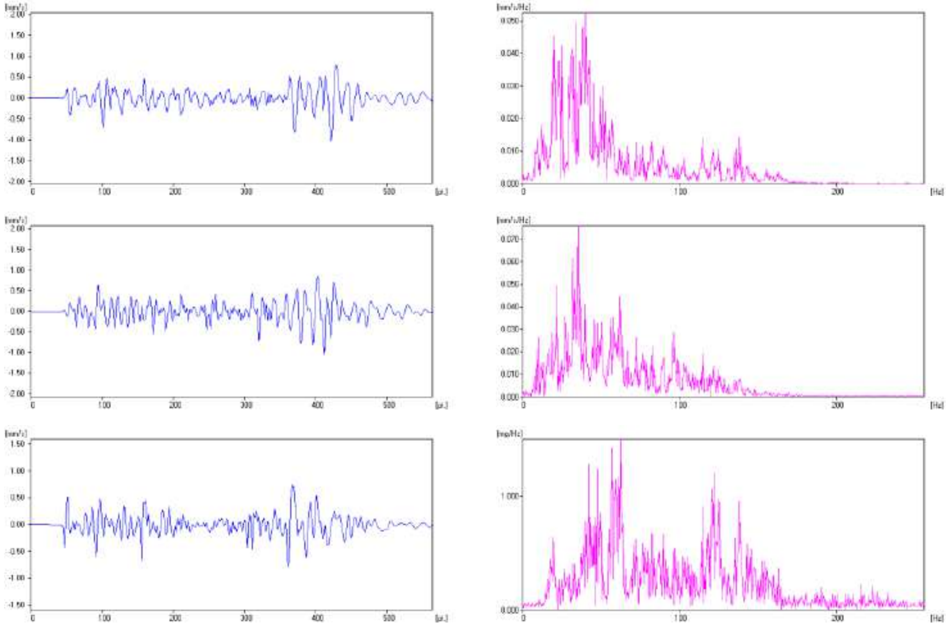


(**a**) (**b**)

Fig. 6. (a) separated epoch above the threshold of 1 mm/s on the NS component for the first measurement (b) separated epoch above the threshold of 1 mm/s on the EW component for the first measurement.

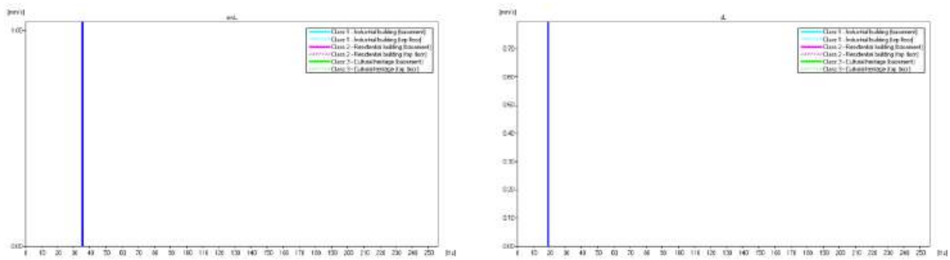
The frequency content of the threshold is approximately 60 Hz which makes use for the comparison of the threshold values with the values defined by the standard DIN 4150-3.

For the second measurement the same procedure is applied and the results of the measurements according to the same principle are presented on the Fig. 7 and Fig. 8.



(**a**) (**b**)

Fig. 7. (a) Traces of the part of the signal with the blast of the second measurement with NS, EW and Z component going from top to the bottom of the figure (b) Corresponding spectral diagrams of the NS, EW and Z component going from top to the bottom of the figure.



(**a**) (**b**)

Fig. 8. (a) separated epoch above the threshold of 1 mm/s on the NS component for the second measurement (b) separated epoch above the threshold of 1 mm/s on the EW component for the second measurement.

On the Fig. 7 the part of the signal traces with the blast are shown (a), together with the accompanying spectral diagrams (b) for the second measurement. The spectral characteristics of this blast is somewhat different that the first measurement. On the horizontal components, the frequency content is lower that the first measurement and the most spectral energy is concentrated in the zone up to 50 Hz. For Z component there is again higher frequency content above 100 Hz, up to 150 Hz, while on the horizontal components this spectral content is not significant.

For the purpose of evaluating the velocity values according to the DIN 4150-3 standard, the threshold of 1mm /s is set having in mind the largest recorded values, in order to separate epochs in which these vibration levels exist, together with the accompanying frequency content. The results are presented on the Fig. 8 for the NS component (a), and EW component (b). The frequency content of the threshold is approximately 35 Hz for NS component, and 19 Hz for EW component, which makes use for the comparison of the threshold values with the values defined by the standard DIN 4150-3.

For both measurements, the maximum-recorded values are well below the threshold values even for lowest frequency range of 1 Hz to 10 Hz. For the first measurement, the recorded maximum values in corresponding frequency ranges according to Fig. 6 are 12 times lower than the threshold value for residential buildings and 6 times lower for sensitive buildings. For the second measurement, the recorded maximum values in corresponding frequency ranges according to Fig. 8 are 5 times lower than the threshold value for residential buildings and 3 times lower for sensitive buildings.

The measurement results indicate that the recorded values of vibrations caused by the blasts are well below the threshold values defined by the standard DIN 4150-3 and according to the standard's criteria could not pose any damage to structures on the location of interest.

4. Conclusion

Vibrations caused by explosions during the construction of the tunnel "Iriški venac" were measured in order to estimate possible impact of induced vibrations on the existing structures located above the tunnel. In total two measurements of ground surface vibrations above the tunnel were performed. Measurements of velocity and acceleration were carried out in two independent blasts (February and March 2025).

The measured maximum velocity values were compared with the velocity values according to the standard DIN 4150-3 Vibrations in buildings – Effects on structures, which relates to the effects of vibrations on structures. It was determined that all measured values are less than the values specified in the standard, and that the vibrations caused by the mining operations could not cause any structural damage, not could pose detrimental effect on people in the buildings.

The limitations of the study is that the effects of blast was measured only in two occasions. Although these measurements were performed when the blast location was closest to the site, a more extensive study would be advisable in order to include directivity effects of the blast (Zhang et al. 2022), as well as to address the attenuation of waves in different directions and distances. For this purpose, long-term measurements would be most suitable with sensor settings on more locations. Furthermore, the sensors could be placed in buildings as well.

Since in the particular case the measured values of velocities were well below the damage threshold specified by DIN 4150-3, the recorded vibrations can be considered acceptable. Based on the performed analysis, the velocity values induced by the blast during mining operations were below the permissible levels by the order of several magnitudes.

References

DIN 4150-3:2016-12 Vibrations in buildings - Part 3: Effects on structures, https://dx.doi.org/10.31030/2579353

Norén-Cosgriff, K.M., Ramstad, N., Neby, A., Madshus, C., 2020. Building damage due to vibration from rock blasting. *Soil Dynamics and Earthquake Engineering*, Volume 138, 106331, ISSN 0267-7261. https://doi.org/10.1016/j.soildyn.2020.106331.

Singh, P.K., Roy, M.P., 2010. Damage to surface structures due to blast vibration. *International Journal of Rock Mechanics and Mining Sciences*, Volume 47, Issue 6, Pages 949-961, ISSN 1365-1609. https://doi.org/10.1016/j.ijrmms.2010.06.010.

Zhang, Q., Zhang, Z., Wu, C., Yang, J., Wang, Z., 2022. Characteristics of Vibration Waves Measured in Concrete Lining of Excavated Tunnel during Blasting in Adjacent Tunnel. *Coatings*, 12(7), 954. https://doi.org/10.3390/coatings12070954.

Zhou, J., Gao, S., Luo, P., Fan, J., & Zhao, C. (2024). Optimization of Blasting Parameters Considering Both Vibration Reduction and Profile Control: A Case Study in a Mountain Hard Rock Tunnel. *Buildings*, 14(5), 1421. https://doi.org/10.3390/buildings14051421.