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Original scientific paper

Ground vibrations level characterization through the geological strength index (GSI)

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Abstract

This paper analyses the results of trial, construction and quarry blasting, carried out in sediment rock deposits, mainly limestone and dolomite, at different locations in the Republic of Croatia. The division of the three test groups was based on the lithology changes and GSI values of the rock units at these locations. The peak particle velocity measurements with 246 recorded events, was conducted during a long period of six years. Based on the results of seismic measurements, the empirical relationships between peak particle velocity and scaled distance were established for each group. In order to establish a useful relationship between peak particle velocity and scaled distance, simple regression analysis was conducted with the *Blastware* software program from Instantel. The results of this study can be used to characterize ground vibration levels to the environment, through the geological strength index (GSI).

Keywords

Ground vibrations, Blasting, Geological strength index (GSI), Peak particle velocity

1. Introduction

The vibration generated by construction or quarry blasting may have an adverse impact on the environment. The vibration effects vary from human annoying disturbances to structural damage. Scientists and experts in this area agree that the level of excited ground and structure vibrations depends on blasting technology, explosive type and weight, delay-timing variations, site geology, scaled distance, parameters of waves propagating at a site, susceptibility ratings of adjacent and remote structures, and other factors. However, the prediction of particle velocity has a great importance in the minimization of the environmental complaints. Estimating the particle velocity and the other components of ground vibration are very useful in blast design (**Downing, 1985; Kahriman, 2004; Mesec, 2005**).

Conducted blasting at the different locations in the Republic of Croatia has resulted in the determination of ground vibrations on the points where the seismographs were placed. The peak particle velocities on these locations were measured during the bench blast optimization studies, the constructions and bench blasting over the period of six years. Monitoring stations were at a distance between2.40 and 379 m from blasts. For monitoring, Instantel Minimate Series II vibration monitors were used most often, and for analysis, Instantel Blastware Version 8.0 software program were used (**Instantel Inc., 2004**).

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In blasting operations, *ANFO* were used as explosives and *NONEL* detonators were used as initiation systems. Hole lengths were between 4.5 and 27 m, drill hole diameters were 76 to 89 mm, and charge weight per delay were from 0.9 to 272 kg.Finally, the empirical relationship between peak particle velocity and scaled distance were established for each of the three rock mass groups based on the results of seismic measurements (**Mesec et al., 2010**).

Based on a series of blast and seismic measurements, utilizing *SD criteria*, the dependence of peak particle velocity on scaled distance at the given location was empirically determined,

$$PPV = K \cdot (SD)^{-n} \tag{1}$$

Where:
K and n – site factors,
SD – scaled distance (m/kg).

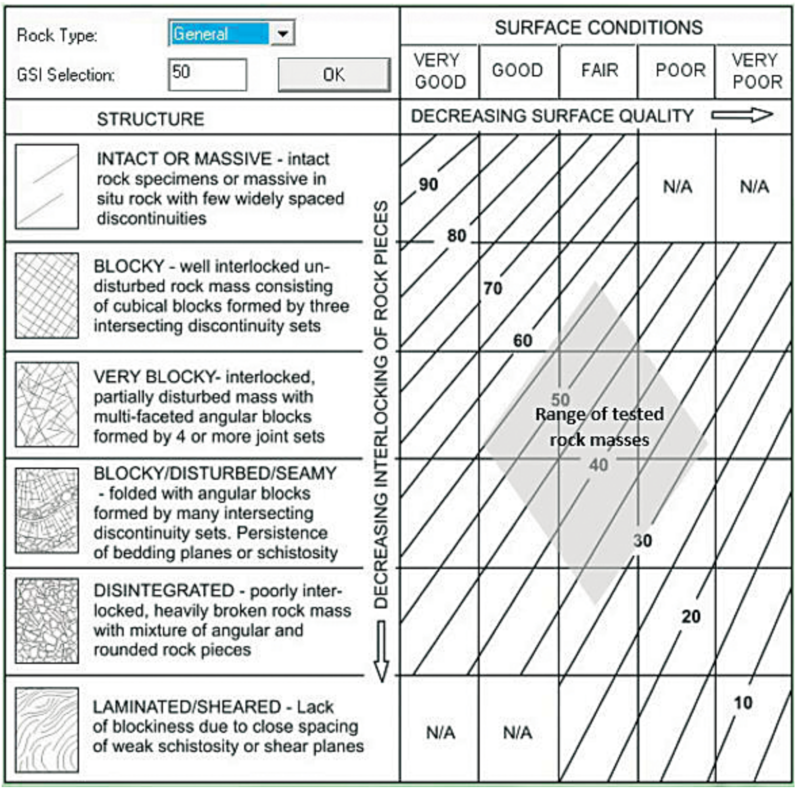
Scaled distance is the parameter which is related to the level of vibrations from the blast,

$$SD = D / (CW)^{1/2} \tag{2}$$

Where:
D – distance (m),
CW – charge weight of explosives detonated per delay (kg).

In this relationship, as distance increases or the amount of explosives decreases, the scaled distance increases. As scaled distance increases the vibrations will decrease (**Siskind, 1980**).

Table 1. Estimate of Geological Strength Index (GSI) (Hoek and Brown, 1997)



This paper also includes the results of measurements from the basic tectonic system at the different rock units. The measurements of the basic tectonic system have resulted in the determination of the geological strength index (*GSI*), as defined by Hoek (**Hoek, 1995**) according to RMR classification by Bieniawski ZT (**Bieniawski, 1989**) and *Q* classification by Barton NR, Lien R and Lunde J (**Barton, Lien and Lunde, 1974**). The *GSI* system is the only rock mass classification system that is directly linked to engineering parameters such as Mohr–Coulomb, Hoek–Brown strength parameters or rock mass modulus. The most important component of the Hoek – Brown system for rock masses with range of tested rock masses is accomplished through the geological strength index (*GSI*) that is defined in **Table 1**.

Rock mass characterization has an important role, not only to define a conceptual model of the site geology, but also for the quantification needed for analyses "to ensure that the idealization (for modelling) does not misinterpret actuality" (**Knill, 2003**). If it is carried out in conjunction with numerical modelling, rock mass characterization presents the prospect of a far better understanding of the mechanics of rock mass behaviour (**Chandler et al., 2004**).

The GSI system has considerable potential for use in rock engineering because it permits many characteristics of a rock mass to be quantified, thereby enhancing geological logic and reducing engineering uncertainty. Its use allows the influence of variables, which make up a rock mass, to be assessed and thus the behaviour of rock masses to be explained more clearly. One of the advantages of the GSI is that the geological reasoning it embodies allows adjustments of its ratings to cover a wide range of rock masses and conditions, but it also allows us to understand the limits of its application. **(Marions and Hoek, 2007**)

2. Rock mass test groups

According to the *GSI* values, investigations and measurements are conducted at different locations in the Republic of Croatia, see **Figure 1**.

Figure 1. Research locations in Republic of Croatia

Table 2. Rock mass test groups

Group	Location	Type of location	Type of rock mass	*GSI* value
I	Macelj	notch at the border crossing	sandstone	30
	Marčan	aggregate quarry	limestone	32
	Seget	aggregate quarry	limestone	37
II	WTC Rijeka 2	construction pit	limestone	43
	Rovinj	construction pit	dolomite limestone	45
	Vukov Dol	aggregate quarry	marbleized limestone	50
III	Špica	aggregate quarry	dolomite limestone	52
	WTC Rijeka 1	construction pit	limestone	55

The division of the three test groups was based on the lithology changes and GSI values of the rock units at these locations, see **Table 2**.

3. Blasts and the ground vibrations measuring, measured and calculated values for all test groups

Following the conducted research and the verification of obtained results, the dependence of peak particle velocity on the scaled distances, $PPV = K \cdot (SD)^{-n}$ has been defined at other locations, and for each rock mass test group as well, see **Table 3**. The number of recorded events for each location was at least 30, so that enough data determined that dependence.

Based on the data stated in Table 3, *PPV – SD* diagrams were drawn as summaries for all three groups, see **Figure 2**.

Figure 3 shows the mine field in construction pit, research location Rovinj.

Table 3. Measured and calculated values, all locations

Group	The number of recorded events	Location	*GSI* value	Oscillation velocity relationship PPV, (mm/s)	r value	Oscillation velocity groups relationship	Group r value
I	90	Macelj	30	$PPV = 4\,331\,(SD)^{-1.81}$	0.89	$PPV = 2\,023\,(SD)^{-1.50}$	0.83
		Marčan	32	$PPV = 138\,(SD)^{-0.63}$	0.92		
		Seget	37	$PPV = 697\,(SD)^{-1.20}$	0.89		
II	64	WTC Rijeka 2	43	$PPV = 809\,(SD)^{-1.52}$	0.89	$PPV = 884\,(SD)^{-1.47}$	0.86
		Rovinj	45	$PPV = 940\,(SD)^{-1.43}$	0.94		
III	92	Vukov Dol	50	$PPV = 508\,(SD)^{-1.37}$	0.89	$PPV = 349\,(SD)^{-1.38}$	0.86
		Špica	52	$PPV = 1\,204\,(SD)^{-1.94}$	0.83		
		WTC Rijeka 1	55	$PPV = 155\,(SD)^{-1.11}$	0.84		

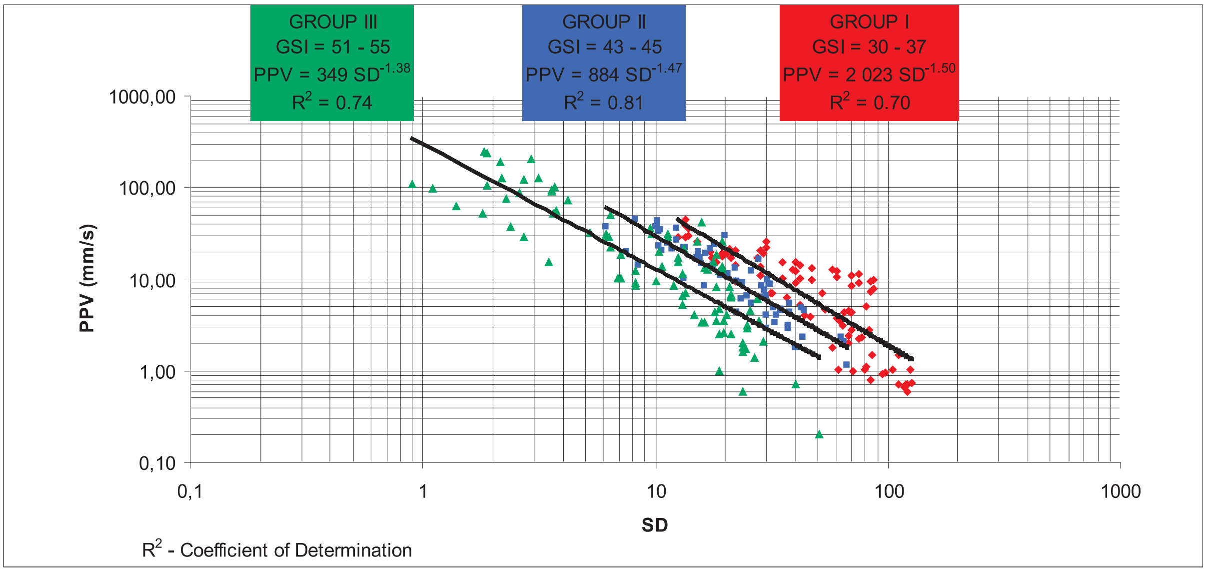


Figure 2. Dependences of peak particle velocity (*PPV*) on scaled distance (*SD*)

Figure 3. Mine field in construction pit, research location Rovinj

4. Scaled distance analysis

In order to establish a useful relationship between peak particle velocity and scaled distance, simple regression analysis was conducted with the *Blastware* software program from Instantel, for each of the three groups separately (**Mesec et al., 2010**). Scaled distance analysis is a useful tool for quick and confident calculation of the maximum charge weight per delay and the minimum safe structure distance for a specific blast site. As a result, each group is given 95 % confidence equations, coefficients of determination and standard deviation for the prediction of PPV on controlled blasting activities, see **Figures 4, 5** and **6**.

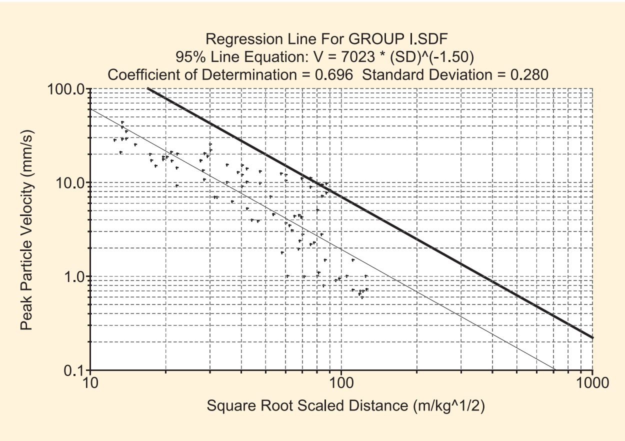


Figure 4. GROUP I: Regression and Line of 95 % Confidence

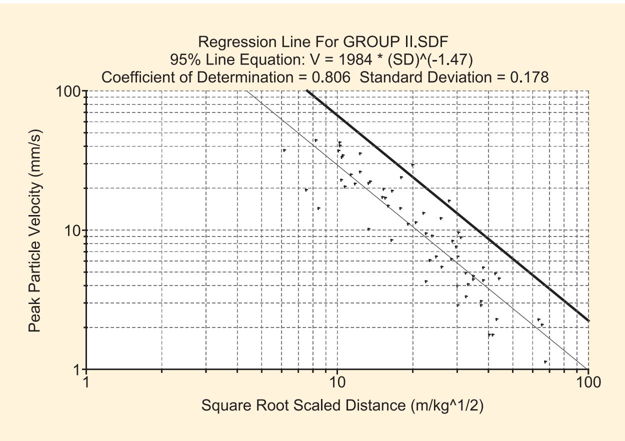


Figure 5. GROUP II: Regression and Line of 95 % Confidence

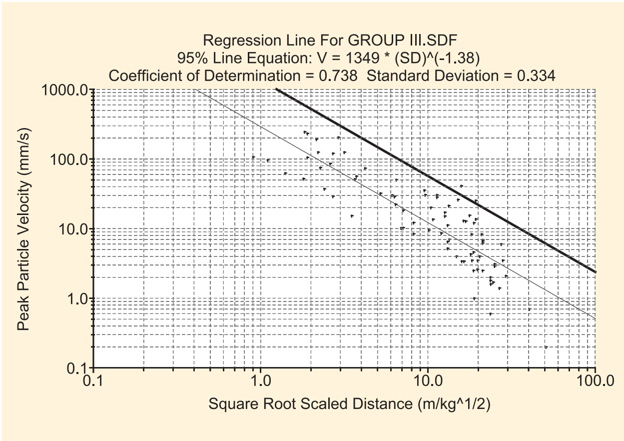


Figure 6. GROUP III: Regression and Line of 95 % Confidence

The scaled distance analysis is summarized in **Table 4**.

5. Conclusions

The results of this paper may be used for some basic vibration prediction and trial blast design starting points, which should be made prior to construction and quarry blasting. As stated in the introduction, the GSI system has considerable potential for use in rock engineering because it permits many characteristics of a rock mass to

Table 4. Scaled distance analysis results

Group	*GSI*	50 % Mean line Equation	r Value	95% Confidence lin Equation	R^2, Coefficient of Determination	Standard Deviation
I	30 - 37	PPV = 2 023 $(SD)^{-1.50}$	0.83	PPV = 7 023 $(SD)^{-1.50}$	0.70	0.280
II	43 - 45	PPV = 884 $(SD)^{-1.47}$	0.90	PPV = 1 984 $(SD)^{-1.47}$	0.81	0.178
III	50 - 55	PPV = 349 $(SD)^{-1.38}$	0.86	PPV = 1 349 $(SD)^{-1.38}$	0.74	0.334

be quantified, thereby enhancing geological logic and reducing engineering uncertainty.

The division of the three test groups was based on the lithology changes and GSI values of the rock units on the investigated locations. The peak particle velocity measurements with 246 recorded events, were conducted over a long period of six years. The empirical relationship with good correlation has been established between peak particle velocity and scaled distance for each rock mass test group as well. Using these relationships, practical charts should be prepared for various charge levels and distances to control blasting for each engineering geological type of sediment rock mass, GSI range of 30 to 55. That is the most common type of rock mass in the Republic of Croatia.Research clearly shows that the ground vibration levels are much higher in the weaker rock masses, respectively to those which have a lower GSI.

This mentioned assertion has a particular importance when the blasting is carried out in urban areas. In these cases, cooperation between the engineering geologist and the mining engineer who designs and performs blasting is more than necessary. Blasting will be carried out successfully if the harmful effects of mining are reduced to allowable limits.For example, according to the value of scaled distance SD = 20, the maximum of peak particle velocity varies from 5 mm/s (group I, GSI = 51 to 55) to the 22 mm/s (group III, GSI = 30 to 37), **Figure 2**. If that relationship in practice is replaced with specific values, e.g., comes out for a distance of 10 meters the endangered object from minefield, charge weight of 0.7 kg per delay would cause the ground vibrations in the mentioned range of 5 to 22 mm/s. The significance of such specified range of the ground vibration level is best reflected in comparison with one of the world-recognized standards, for example DIN standards 4150.

However, it should be taken into consideration that these relationships established just for the prediction of peak particle velocity gives incomplete results because of other geological and blast effects. **To support the reliability of this study, accompanied by the maximum measured peak particle velocities and its principal frequencies should be included**. In this case, the results of this study can be used to characterize ground vibration levels to the environment, through the geological strength index (GSI).

6. References

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SAŽETAK

Karakterizacija intenziteta oscilacija tla geološkim indeksom čvrstoće (GSI)

U ovome radu analizirani su rezultati probnih miniranja, miniranja za graditeljske svrhe i miniranja u kamenolomima. Ta miniranja provedena su u sedimentnim stijenskim masama, pretežno vapnencima i dolomitima, na različitim lokacijama u Republici Hrvatskoj. Podjela na tri grupe zasnovana je na litološkim promjenama i promjenama GSI vrijednosti stijenskih masa na tim lokacijama. Mjerenje maksimalne brzine vibracija rezultiralo je s 246 snimljenih događaja, a provedeno je kroz dugi period od šest godina. Temeljem rezultata seizmičkih mjerenja utvrđen je empirijski odnos između maksimalne brzine vibracija i skalirane udaljenosti za svaku grupu. U svrhu određivanja korisnoga odnosa između maksimalne brzine vibracija i skalirane udaljenosti provedena je jednostavna povratna analiza pomoću Instantelova programa. Rezultati ove studije mogu se koristiti za karakterizaciju intenziteta oscilacija tla na okoliš geološkim indeksom čvrstoće (GSI).

Ključne riječi
vibracije tla, miniranje, geološki indeks čvrstoće (GSI), maksimalna brzina vibracija