Rudarsko-geološko-naftni zbornik	Vol. 15	str. 57-62	Zagreb, 2003.

UDC 624.19:622.235:534.64
UDK 624.19:622.235:534.64

Original scientific paper
Originalni znanstveni rad

DYNAMIC INFLUENCE CAUSED BY CLOSE BLASTING ON PRIMARY AND SECONDARY SUPPORT SYSTEM IN TUNNEL "SV. ROK"

ZVONIMIR ESTER, MARIO DOBRILOVIĆ, DARKO VRKLJAN

Faculty of Mining, geology and Petroleum Engineering, , University of Zagreb, Pierottijeva 6, Zagreb, Croatia

Key words: tunnel, blasting, seismic effects, primary and secondary tunnel support system.

Ključne riječi: tunel, miniranje, sizmički utjecaji, primarna i završna tunelska podgrada

Abstract

At the construction site of the road tunnel Sv. Rok, the second, left tunnels tube is being constructed parallel to the unfinished right tunnel. The part of right tunnel tube is supported with primary support system according to NAMT, the second part is supported complete with concrete. Distance between axes of the tunnel tubes is approximately 35 m. Drifting of the left tube is being done by blasting. A potential problem of damaging the surrounding rock and support system was recognized. It is well known that the ground vibration particle velocity due to a blast is a measure of damage on the nearby construction. The three component seismographs were used to measure ground oscillation velocities in the right tunnel tube. Total of 30 measurements were executed and 720 values were processed (including all three component oscillation velocities). Maximum ground oscillation velocity recorded was 232.061 mm/s. This paper brings conclusion derived from monitoring data achieved at close proximity to the blasting area, damage level criteria for the rock mass and support system and discusses how these results could assist further development in the control of blasting technique.

Sažetak

Prilikom izgradnje cestovnog tunela Sveti Rok, lijeva tunelska cijev probija se paralelno nedovršenoj desnoj cijevi. Desna tunelska cijev djelomično je podgrađena primarnom podgradom prema NATM (Nova Austrijska Tunelska Metoda) a djelomično završnom betonskom oblogom. Udaljenost između osi tunelskih cijevi je približno 35 m. Iskop lijeve tunelske cijevi je miniranjem te su moguća oštećenja okolne stijene i podgradnog sustava. Poznato je da su brzine oscilacija stijene uzrokovane miniranjem mjera za određivanje mogućih oštećenja na ugroženim objektima i konstrukcijama. Prilikom mjerenja brzina oscilacija stijene u desnoj tunelskoj cijevi, korišteni su trokomponentni seizmografi. Iz 30 mjerenja obrađeno je 720 podataka o brzinama oscilacija (uključujući sve tri komponentne brzine oscilacija). Najveća izmjerena brzina oscilacija iznosila je 231.061 mm/s. U radu su dani zaključci bazirani na mjerenjima na malim udaljenostima od minskog polja o dozvoljenoj brzini oscilacija u odnosu na moguća oštećenja stijenske mase i podgradnog sustava u svrhu razumjevanja odnosa između minerskih parametara, brzina oscilacija stijene i nastanka mogućih oštećenja pri miniranju na malim udaljenostima u podzemlju.

1. Introduction

Amount of explosive charge which does not cause damage of the rock and supporting system is estimated upon:

- predicted oscillation intensity as a function of the amount of explosive charge per level of ignition,
- Distance between blasting field and supporting system,
- Attenuation of seismic waves as a consequence of geological characteristics of a rock,
- Maximum allowed level of ground oscillation.

Connection between maximum oscillation velocity at a measuring point, amount of explosive charge per level of ignition and a distance from a blasting point to a measuring point is given by empiric formula after M. A. Sadovski (Krsnik 1989).

$$v = k\left(\frac{\sqrt[3]{Q}}{R}\right)^n \text{ (cm/s)} \qquad (1)$$

where

v ground oscillation velocity (cm/s), Q amount of explosive charge used for detonation (kg), R distance between measuring point and blasting field (m), k and n constants depend on the geological characteristics of a rock

Based on the results of measuring of the oscillation velocities and consequential damages of rock mass in surroundings of the blast hole, a ground oscillation velocity was estimated for Swedish gneiss and granite which causes increase in rock deformations (Holmberg 1979). Damage was noticed up to 32 m away from the blasting point by velocity v = 700 mm/s.

Langefors and Kihlström suggested the level of *v*= 300 mm/s for unsupported tunnels constructed in rocks like granite.

I. D. Isaac suggested level of *v* = 450 mm/s based on measurements taken by construction of underground engine room of the power plant Dinorwic (Isaac et all. 1981).

T. R. Yu and S. Vongpaisal suggested the criterion for estimation of allowed ground oscillation velocity for underground constructions (Yu et all. 1998) given by blast damage index:

$$BDI=\frac{vdC}{K_t T} \qquad (2)$$

where BDI (Blast Damage Index), v ground oscillation velocity (m/s), d rock density (g/cm^3), C compressive pulse velocity in a rock (km/s), K_1 constant of rock quality, T dynamic compressive consistency of rock (MPa).

Value of BDI index varies between 0.125, with no damage occurring, and 2 when great damage occurs related to ground oscillation velocity v = 85 mm/s (no damage) and v = 1750 mm/s (rock collapse).

A. K. Chakraborty had applied the suggested criterion by construction of underground chambers in basalt rock and found out that the level of possible damages v = 85 mm/s is far too low (Chakraborty et all. 1998).

For the orientation about possible support structure damage, standard DIN 4150 is applied.

Table 1.; subsection 1, under DIN 4150-3-1999-02, gives values of oscillation velocity for support structures, like armour-concrete columns, massive foundations and other.

Table 1. DIN 4150-3 1999-02, part 3
Tablica 1 DIN 4150-31999-02, part 3

	Support structures			
Frequency (Hz)	1-10	10-50	50-100	over 100
Max. oscillation velocity V_{max} *(mm/s)*	40	40-80	80-100	min. 100

2. Expected oscillation velocities calculation

Calculation of expected oscillation velocity for second tunnel tube was based on measurements taken during construction of the first tube.

During blasting on location 198+274, observations of blasting seismic effects have been executed on two Mini-Seis II 2D2G Digital Seismographs S/N on two observation points. The rock itself is of II tunnel category.

On figure 1 tectonic structure of the rock on location 198+270-198+290 m is shown.

Figure 2. gives trajectories of component oscillation velocities on location 198+274.

Drifting profile was 100 m^2, and excavations itself was done with Tamrock Paramatic tunnel machinery. 160 blasting holes were 45 mm in diameter 45 mm and 3,8 meters in length.

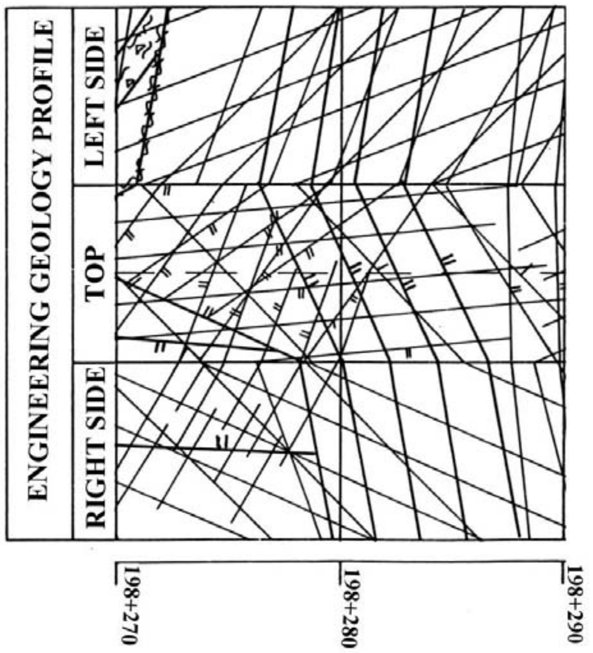

Figure 1. Tectonic structure of the rock on location 198+270-198+290 m

Slika 1. Tektonski sklop stijenske mase 198+270-198+290 m

Blasting holes were charged with bulk ANFO explosives, using mechanical charger DYNO Anol 500 cc. Contour blasting holes were charged with Amonex and Konturvitezit explosives combination. Ignition was non-electric system NONEL LP.

Measurement Points (MP) were placed:

MP-1 on 72 meters distance from top of the site, on the right hand side of the tube.

MP-2 on 107 meters distance from top of the site, on the right hand side of the tube.

Ground velocity oscillation in MP-1 and MP-2 are shown in Table 2.

Table 2 Measurements results on station 198 +274 m

Tablica 2. Rezultati mjerenja na stacionaži 198 +274 m

Measurement Point	MP-1	MP-2
Instrument No	1263	1264
Distance from top of site	72	107
Component ground oscillation velocity (cm/s) v_l	1.6510	1.2192
Component ground oscillation velocity (cm/s) v_v	2.7432	1.0922
Component ground oscillation velocity (cm/s) v_t	1.6002	0.9906
Resulting ground oscillation velocity (cm/s) v_r	2.9210	1.6383

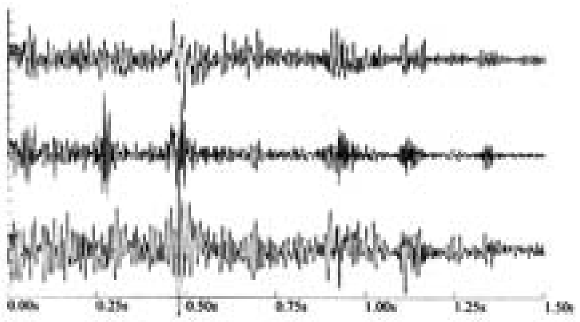

Figure 2. Trajectories of component oscillation velocities on location 198+274

Slika 2. Trajektorije komponentnih brzina oscilacija na stacionaži 198+274

Through frequency analysis for each component velocity oscillation of the dominant frequency was determined. Dominant frequencies range from 51,2 to 265 Hz, favorable result under current standards.

On basis of measurements, counting with max quantity of explosive charge by approximately 40 kg for degree of blasts, expected oscillation velocity for R=25 meters from top of blasting site v_{exp} = 10 cm/s was calculated.

Expected oscillation velocities fall inside DIN 4150-3 (Table 1.) for measurements results and frequency oscillations in tectonic structure of rock mass II category.

3. Measurements on construction of second tunnel tube – primary support system

For determination of blasting effects on already built right tunnel tube, systematic observations of seismic effects of blasting by construction of left tunnel tube were conducted.

Rock in right tunnel tube, of II tunnel category, was supported with primary support system suited for II tunnel category: anchors, nets and sprayed concrete.

3.1 Geological characteristics of rocks

The rock mass in the observation area consists of carbonate sediments of Upper Dogger, characterized by a sequence of dark gray limestone with interlayers of light gray dolomite with sporadic clay layers in between. Bed thickness varies from 15 to 80 cm. Clay layers are up to 50 mm thick. Clay is black, with organic matter. It looks greasy and shiny. Clay layers played a role of strike-slip planes for block movement.

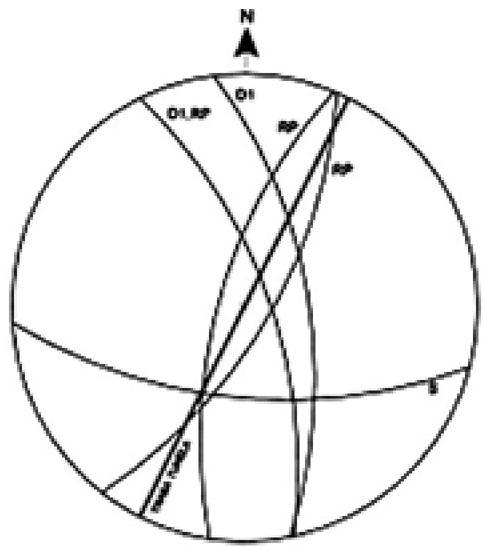

Figure 3. A contour diagram

Slika 3. Konturni dijagram

S.........bedding
D1......fractures
RP......fault

A structural framework is defined with several systems of discontinuities with general orientation 80-90/75-90, 290-310/70-80, 100-110/60-80, general bedding dip 170-200/50-60 and fault zones. Discontinuities are marked by calcite veins or clay, or calcite and clay. Discontinuity length varies from 1 m to 20 m. Sides are commonly not eroded, poorly corroded, rough or smooth where there is clay.

Water in such zones occurs as moisture or drip water. Running water is commonly connected to fault zones and existing caverns, and with particular discontinuities.

A contour diagram of discontinuities for location 200+104 is given in figure 3.

3.2 Oscillation velocity measurements

Drill scheme-blast pattern, shown on Figure 4 was used, with hole depth of 380 cm, 105 holes plus 2 central holes of 76 mm in diameter. Average specific use of explosives was 1,3 kg/m3. Explosive charge was Amonal patronized explosive of 38 mm in diameter and Donarit explosive with same diameter patrons. Gurit explosive of 17 mm diameter in plastic tubing was used for contour blasting. By inspection of earlier constructed rock, more than 70% of contour blasting holes are visible, accounting for well chosen parameters of contour blasting. Ignition was done by non-electric system NONEL.

In total 12 measurements were executed in Right tunnel tube. Figure 6 shown placement of measurement point (MP) and blast field (BF) in right tunnel tube.

Table 3 gives basic data on mine-fields and measurement results.

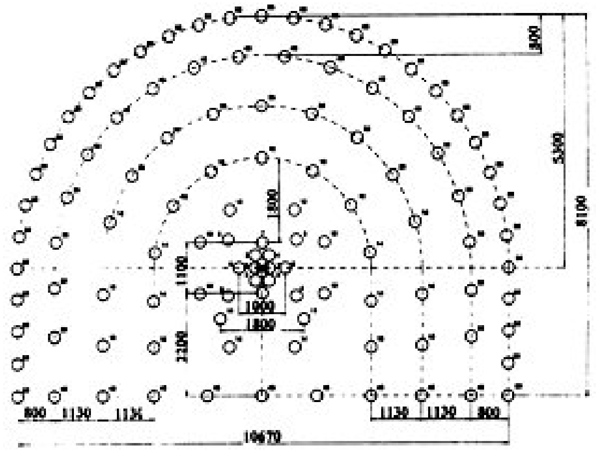

Figure.4. Blast pattern-large hole cut

Slika 4. Minsko polje-paralelni-cilindarski zalom

Table 3. Measured maximal ground oscillation velocities in right tunnel tube

Tablica 3. Maksimalne izmjerene vrijednosti brzina oscilacija u desnoj tuneskoj cijevi

Distance between MP's (m)	Explosive charge Quantity (kg)	Number of millisecond degrees of blasts	Measured oscillation velocity – maximum v_r (cm/s)
25.55; 34.58	448	22	8.87
25.53; 34.87	386	23	2.10
25.56; 39.05	407	23	5.35
25.20; 39.05	406	23	7.92
24.80; 34.42	522	22	11.51
25.34; 39.56	487	23	7.15
25.58; 34.54	406	23	5.32
24.70; 38.65	407	23	7.76
25.38; 29.55	398	23	6.43
24.86; 29.65	514	21	12.06
25.18; 29.57	435	23	7.21
25.35; 38.93	412	22	8.34

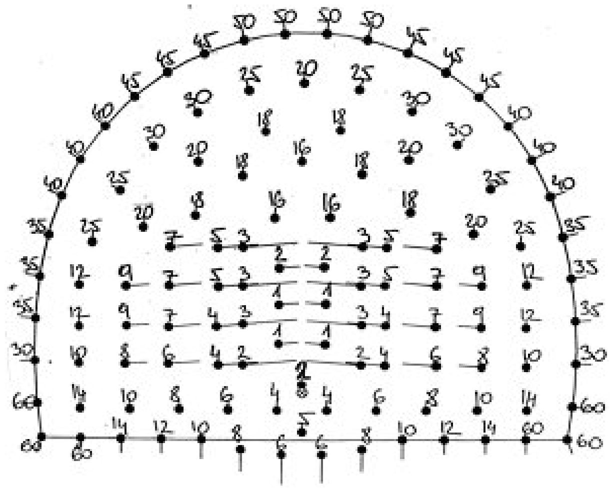

Figure.5. Blast pattern-V cut

Slika 5. Mnsko polje- V zalom

Based on the observation data we conclude that the ground oscillation velocities reached, at least at one detonation level, values above allowed velocities according to standards for industrial objects. Nearly each blast triggered exfoliation of sprayed concrete along the lower left side of the right tunnel tube. This phenomenon, known as Hopkinson's effect, was noticed by Johansson et all. (1970).

Later on, influence of Hopkinson's effect on rock samples was tested in a laboratory (McCarter et all.1993, Katsuyama et all 1993).

In case of sufficient kinetic energy exfoliation of sprayed concrete occurs on a free surface. It is assumed that velocity of free surface movement above 10.0 cm/s causes exfoliation of concrete on the tunnel side.

Two applicable solutions of preventing further damage of the support system (sprayed concrete) are:

1) to reduce the maximum amount of explosive charge per detonation level from previous 70 kg to a maximum of 40 kg, keeping the ground oscillation velocity below 10.0 cm/s with permanent monitoring.

2) to reinforce the support system in the area of exfoliation and sprayed concrete.

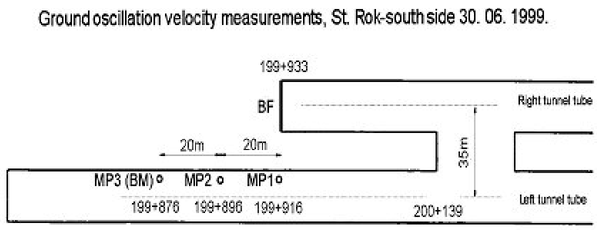

Figure 6. Measurement point placement in right tunnel tube

Slika 6. Pozicije mjesta opažanja u desnoj tunelskoj cijevi

Solution no. 2 was accepted and Croatian Motorway Authority (CMA) choose to support whole section of the tunnel with steel nets and 15cm thick layer of sprayed concrete.

Figure 7 shown characteristic trajectory imprint of component oscillation velocities

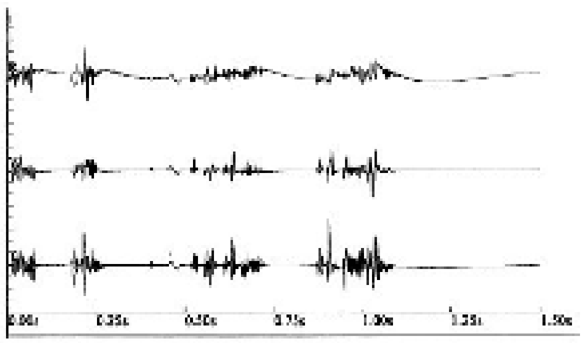

Figure 7. Characteristic trajectory imprint of component oscillation velocities

Slika 7. Karakteristični snimak trajektorija komponentnih brzina oscilacija

4. Measurements during construction of second tunnel tube – Final support system

Oscillation velocity measurements on final concrete support layer have been conducted on 4 observation points. Distribution of measurement point is shown on figure 8. Figure 5. shown the blast pattern used in all further measurements.

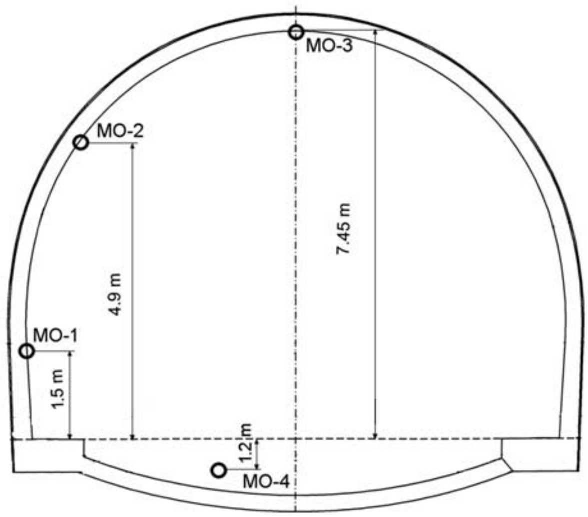

Figure 8. Measurement points pattern on concrete support surface

Slika 8. Raspored mjesta opažanja na završnoj betonskoj oblozi

Test blasting results are displayed in Table 4.

Table 4 Oscillation velocities of concrete in trial blasting
Tablica 4 Brzine oscilacija na završnoj betonskoj oblozi prilikom probnog miniranja

Explosive charge quantity (kg)	No. of millisecond degrees of ignition	Amount of explosive charge per degree (kg)	Maximum measured oscillation velocity – in MP v_r (cm/s)
275	12	39	15.46 MO-2
286	12	33	11.81 MO-2
319	14	28	6.856 MO-3
260	14	22.64	6.920 MO-1
275	14	22.64	5.249 MO-1
284	14	19.76	3.102 MO-1
333	20	22.64	3.290 MO-1
317	19	22.64	3.131 MO-2

Data from the Table clearly shows that resulting velocities exceeded the expected level of 10 cm/s, without noticeable damage to final concrete support layer. Explosive charges used were of 39 and 33 kg per degree of ignition. Dynamic impact of rock mass caused complete concrete support layer to vibrate for 4-5 seconds.

Figure 9. gives trajectories of component oscillation velocities for concrete taken from station 202+213 in Left Tunnel Tube.

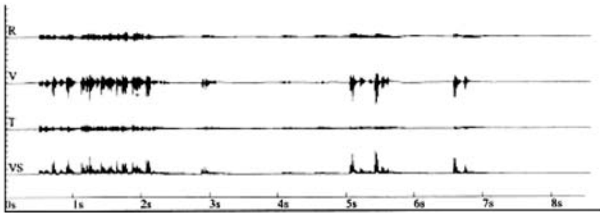

Figure 9. Trajectories of component oscillation velocities for concrete taken from station 202+213 in Left Tunnel Tube.

Slika 9. Trajektorije komponentnih brzina oscilacija na završnoj betonskoj oblozi, stacionaža 202+213 u lijevoj tunelskoj cijevi

CMA's request was to lower vibration intensity to 4 cm/s, in fear of damage to hydro-isolation laid between Primary and Final concrete support system.
Request was achieved with diminishing amount of explosive charge used per degree of ignition and rising no. of millisecond delay and total number of blasting holes.

From starting 39 kg, amount of explosive charge was diminished to 22,64 kg, with millisecond ignition intervals rising from 12 to 20.
End result is acceptable oscillation velocity in concrete of slightly over 3 cm/s.

5. Conclusion

Lacking objective criteria, and based on scarce literature data treating harmful interactions of close blasting on already laid Primary and Final Support in tunnel, great number of seismic effect measurements have been performed in Sv. Rok Tunnel drifting, aimed at deterblasting the level of oscillation velocities not causing deformation and damage to Support system.

With oscillation velocities exceeding 8 cm/s, exfoliation of sprayed concrete was noted on Primary Support. Quality of sprayed concrete is an open topic.

Currently, on Highway Zagreb-Split site, 12 tunnels with parallel tunnel tubes and axis distance of 25 meters are constructed.

Constant monitoring is performed, and in oscillation velocities of 23.206 cm/s no damage to Primary Support and sprayed concrete was noted. Possible deformations increase in the rock and support on which measuring was done, can be defined upon analysis of cores before and after blasting or by seismic tomography.

With oscillation velocities exceeding 15 cm/s no damage to Final Support concrete layer was noted. Dynamic impact of rock mass to concrete layer can cause damage to hydro-isolation. Finally, 4cm/s oscillation velocity value is in-fact assumptious, since it is not based on testing of hydro-isolation post-blasting.

Received: 10.07.2003.
Accepted: 30.09.2003.

References

Chakraborty, A. K., Raina, A. K., Ramulu, M., Jethwa, J. L., Gupta, R. N. (1998.) *Lake Tap at Koyna.* World Tunneling, November, pp 456-460.

Holmberg, R., Persson, P.A. (1979.): *Design of tunnel perimeter blasthole patterns to permit rock damage,* Proceedings Tunnelling '79, IMM, London, 2870-2883.

Isaac, I. D., Bubb, C. (1981.): *A study of blast vibrations part 1.* Tunnels & Tunnelling, July, pp 35-41.

Johansson, C. H., Persson, P. A. (1970.): *Detonation of High Explosives.* Swedish Detonic Research Foundation, Stockholm, pp 352.

Krsnik, J. (1989.) *Miniranje,* Sveučilište u Zagrebu, pp 178.

McCarter, M. K., Kim, D. S. (1993.): *Influence of shock damage on subsequent comminution of rock.* Rock Fragmentation by Blasting, Rossmanith (ed), Balkema, Rotterdam, pp 63-69.

Yu, T. R., Vongpaisal, S. (1996.): *New blast damage criteria for underground blasting.*CIM Bulletin, Vol. 89, N° 99, pp 139-145.