Karel HOLUB[1], Jaromír KNEJZÍK[2], Jana RUŠAJOVÁ[3]

SEISMOLOGICKÁ POZOROVÁNÍ NA DISKRÉTNÍCH STANOVIŠTÍCH V PRŮBĚHU SEISMICKÉHO EXPERIMENTU SUDETES 2003

SEISMOLOGICAL OBSERVATIONS AT DISCRETE SITES DURING THE SEISMIC EXPERIMENT SUDETES 2003

Abstract

The seismic waves generated by hole shots and quarry blasts performed during the seismic experiment SUDETES 2003 on the territories of the Czech Republic and Poland were examined.The waves were recorded at several discrete sites of observation ranging in the distance from 46 km to 266 km. Analyses of seismograms indicated the existence of three basic groups of body waves, i.e. Pn, Pg and Sg with apparent velocities of propagation 7.76 km/s, 6.05 km/s and 3.55 km/s, respectively. These velocities are rather higher than the values found by different authors during previous observations. It is suggested that these waves recorded at larger epicentral distances are refracted (dipping) waves travelling through the crystalline basement.

Introduction

In 2003 a massive international cooperation continued in the frame of the SUDETES 2003 seismic experiment which linked to previous field experiments mentioned in Guterch et al. (2003 and 2003a) and Grad et al. (2003). Some of the goals of seismological observations guaranteed with the Institute of Geonics AS CR (ÚGN) in Ostrava supposed the participation in this experiment during June 2003, too. It was anticipated that the observational material would be mostly obtained at the temporary seismic station in Rašovice (RAS) in southern Moravia in the course hole shots and quarry blasts distributed along profile S04 (see Fig. 1). Contrary to our assumption, the prevailing number of seismograms was gathered from individual hole shots performed on the Polish territory along profiles S01, S02, S03, S05 and S06 (see Grad et al., 2003), which were recorded at several seismological stations distributed on the territory of northern Moravia. On the one hand, these stations were a part of the Czech national seismic network (CNSN), i.e. the stations Moravský Beroun (MORC), operated by the Institute of Physics of the Earth at Masaryk University (IPE) in Brno and Ostrava-Krásné Pole (OKC), operated by ÚGN AS CR and VŠB-TU Ostrava and temporary stations Slezská Harta (SHAC) and Javorník (JVRC), on the other.

The SUDETES 2003 seismic experiment provided suitable opportunity to test a new data acquisition system PCM3-ESP2, to set up travel-time curves of body waves Pn, Pg and Sg and to derive their apparent propagation velocities. Comprehensive information on the results obtained during refraction experiment SUDETES 2003 carried out in June 2003 is presented.

Some technical details

a) Borehole shots and quarry blasts

Two types of seismic sources were used during field experiments. A standard scheme of boreholes at every site was applied (5-10), the depth of which varied (30-40 m), the total amount of explosives at individual hole shots, which were taken into account, was in the range of 50-250 kg. In addition special quarry blasts were carried out. Only two quarry blasts (Nos 1 and 8) of 400 kg fired on the profile S04, were reasonable for our purposes while the other blasts generated only weak seismic signals disappearing on the background of the ambient noise.

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[1] RNDr., DrSc., Ústav geoniky AV ČR, Studentská 1768, Ostrava, holub@ugn.cas.cz
[2] Ing., CSc., Ústav geoniky AV ČR, Studentská 1768, Ostrava, knejzlik@ugn.cas.cz
[3] Ústav geoniky AV ČR, Studentská 1768, Ostrava, rusajova@ugn.cas.cz

The basic data of individual hole shots and quarry blasts are given in Table 1. and their position on the region under investigation is displayed in Fig.1.

Tab.1 Overview of the shot point parameters

Shot number[1]	Shot point number	Date (yyyy.mm.dd)	Time (UTC) (hh:mm:ss.sss)	Latitude N (°)	Longitude E (°)	Charge (kg)
44090	1	2003.06.04	17:50:01.843	49.734280	15.760150	400
43060	2	2003.06.04	22:30:00.000	50.524627	16.617047	50
42080	3	2003.06.04	22:40:00.000	51.963022	16.397602	250
43070	4	2003.06.05	00:40:00.000	50.775958	16.707269	150
41140	5	2003.06.05	22:20:00.000	51.392980	16.034777	250
45020	6	2003.06.05	22:40:00.000	50.581300	18.215.325	150
45010	7	2003.06.05	22:50:00.000	50.650294	17.514211	250
44110	8	2003.06.06	03:50:01.183	49.266916	16.744416	400
46020	9	2003.06.06	22:20:00.000	51.455991	18.020575	250
45030	10	2003.06.06	22:40:00.000	50.458080	19.305741	150

acc. to Grad et al. 2003.

b) Seismic stations

The supporting point in our observations was seismic station Ostrava-Krásné Pole (OKC), which were supplemented by data of seismic station MORC and temporary stations SHAC nad JVRC situated in northern Moravia and RAS, which was placed in southern Moravia on the profile S04.

Tab2. Co-ordinates of seismological stations

Station			Latitude	Longitude	Height
Symbol	Name	Code	N (°)	E (°)	(m)
A	Ostrava – Krásné Pole	OKC	49.8353	18.1423	+250
D	Moravský Beroun	MORC	49.7768	17.5425	+743
C	Slezská Harta	SHAC	49.8880	17.5796	+493
B	Javorník	JVRC	50.3868	17.0044	+300
E	Rašovice	RAS	49.0237	16.9432	+344

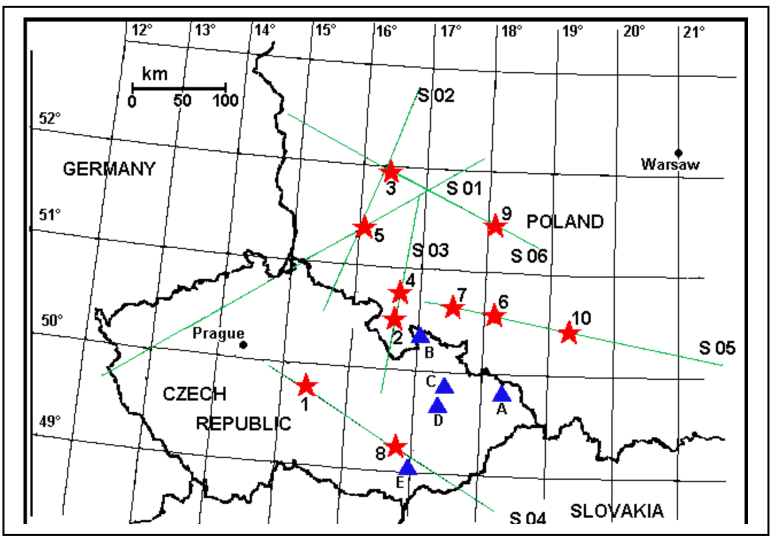

Fig.1 Scheme of and seismic stations (▲) and shot points (★) distribution on the profiles S01–S06 during seismic experiment SUDETES 2003. A–OKC, B–JVRC, C–SHAC, D–MORC and E–RAS.

c) Instrumentation

Since the instrumentation of both stations of the Czech national seismic network, i.e. OKC and MORC is given, e.g in www.ig.cas.cz, we will pay our attention to the equipment of temporary seismic stations JVRC, SHAC and RAS, operated by the Institute of Geonics AS CR.

The seismometers SM-3 (T_S = 2.0 s and Ds ≈ 0.7) were used at all three-component stations, i.e. RAS, SHAC, and JVRC. Data basic acquisition system was represented by the type of apparatus PCM3 (Knejzlík 2000) operating in triggered regime.

For the current grant project dealing with observations of quarry blasts, induced seismic events and microearthquakes on the territory of the Moravo-Silesian region a new modification of the data acquisition apparatus PCM3-EPC2 was constructed. Regarding the seismic experiment SUDETES 2003 which was planned to be performed along several refraction profiles in the Czech Republic and Poland as well, we decided to use these shot-hole explosions and some quarry blasts for testing the apparatus mentioned above. A site for observations along profile S04 was selected in southern Moravia near quarry Ochoz near Brno (shot point No. 24, r ≈ 31 km). The further shot point along this profile (No. 25) preliminarily situated in a quarry near Kyjov was not allowed for explosions, under the use of a greater mass of explosives.

The basic parameters of apparatus PCM3-EPC2 are as follows:

❑ dynamic range of the A/D convertor	90 dB
❑ sampling frequency	100 Hz
❑ timing derived from the Time normal DCF 77.5 kHz	
❑ measuring range of amplifiers	0.5; 1; 2; 4; 8; 16; 32 mm/s
❑ range of amplifier frequencies	0.05 / 30 Hz
❑ data format	ESSTF/2
❑ record	triggered and/or continuous.

As a part of these field measurements a special experiment was performed, which was aimed at the trial remote change of triggered regime of recording at the stations Slezská Harta (SHAC) and Javorník (JVRC) to the continuous recording via GSM network. This attempt was successful, and therefore during field measurements these shot-hole explosions at both stations were recorded continuously. The results of this trial testing pointed out to the possibility of applying triggered and/or continuous record when needed. Continuous record is reasonable, especially when a weak quarry blast is expected, the firing time of which is defined only approximately.

Data interpretation

The interpretation of all seismograms recorded from individual shot-points was relatively complicated due to the propagation of seismic rays through different structures of medium. On the contrary, the interpretation of seismograms obtained during refraction profiling seems to be fairly easier because individual traces are more or less close to each other. Nevertheless, some gradual changes of waveform occur also due to variations of the local seismogeological conditions at individual sites of observations. Therefore, we only present first arrivals of Pn, Pg and Sg waves picked up on seismograms, the latter arrivals of body waves were not interpreted in detail, besides the reflections from the Moho discontinuity (PmP), which are observed only occasionally. These arrivals were detected with a delay of about 2.2-2.5 seconds after the first arrivals of Pg waves at the distances around r = 90-120 km.

Estimation of the quality of individual onsets documented that relatively sharp onsets of Pg waves were observed up to distances of about 80-90 km from the shot-point, however, the quality depended also on the charge mass of blasts. On the other hand, onsets of Sg waves were identified with less reliability due to the higher level of reverberations caused by the foregoing waves. The Sg travel-time curve which appears above the Pg branch is supposed to be a shear wave with a similar path to Pg. The horizontal trace amplitudes are usually doubled those of Pg, while on vertical components the shear wave amplitudes are approximately a half of the compressional waves. At distances r > 145 km very weak onsets of the Pn waves were observed at several sites only, while corresponding waves Sn were not identified at all.

Two seismograms in Fig. 2 were recorded from the same shot-point being displayed here by meas of program EVENT (Musil 1994).

a **b**

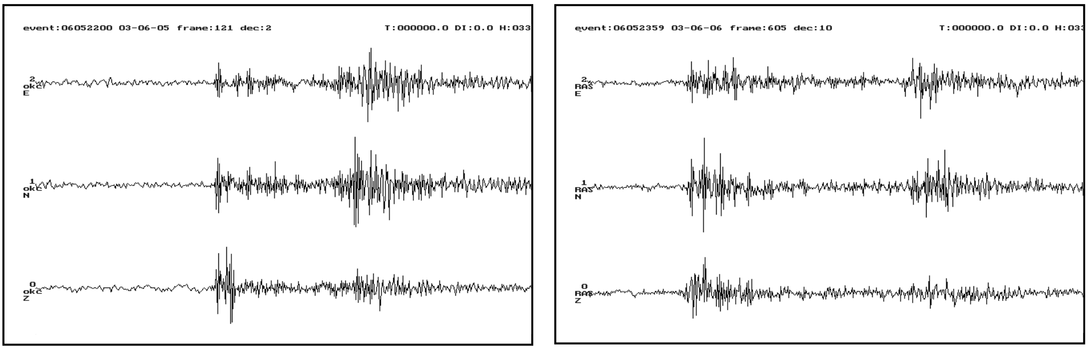

Fig.2 Seismograms recorded at the seismic stations: a – OKC, hole shot No. 45010, r = 101.01 km, b – RAS, hole shot No. 45010, r = 185.4 km (time is given in CET).

Travel-time curves of body waves

A plot of arrival times of observed waves Pg and Sg in Fig. 3 indicated that most points are concentrated along almost linear time-distance segments of travel-time curves. Nevertheless, these waves could be considered as refracted waves dipping with very slow depth-velocity increase. Such almost linear curves are consistent with subhorizontal layers in the uppermost part of the Earth´s crust. Due to the distribution of shot-points as the seismic stations in the extensive area under investigation, some variation of seismic wave velocities with the azimuth could be expected, but the determination of these deviations was not carried out. For this purpose a dense net of profiles and sufficient number of hole shots would be desirable.

All three branches of travel-time curves were approximated by straight lines and using their resulting parameters, i.e the inverse value of apparent velocity of the corresponding seismic wave (1/v), the absolute value of the point of intersection on the abscissa (a) and the coefficient of correlation R^2 were derived. Then the general equation of straight line is as follows:

$t = a + r/v$, (Eq. 4.1)

where t …the arrival time in (s)

a …the absolute value of the point of intersection in (s).

r …the epicentral distance in (km)

v …the apparent velocity of the appropriate seismic wave in (km/s).

Using the method of regression analysis, values of individual parameters were derived and equations of approximative straight lines are figured in the following terms:

Pn: $t(s) = 5.685 + r/7.758$ $R^2 = 09891$ (Eq. 4.2)

Pg: $t(s) = 0.634 + r/6.050$ $R^2 = 0.9985$ (Eq. 4.3)

Sg: $t(s) = 1.525 + r/3.551$ $R^2 = 0.9974$ (Eq. 4.4).

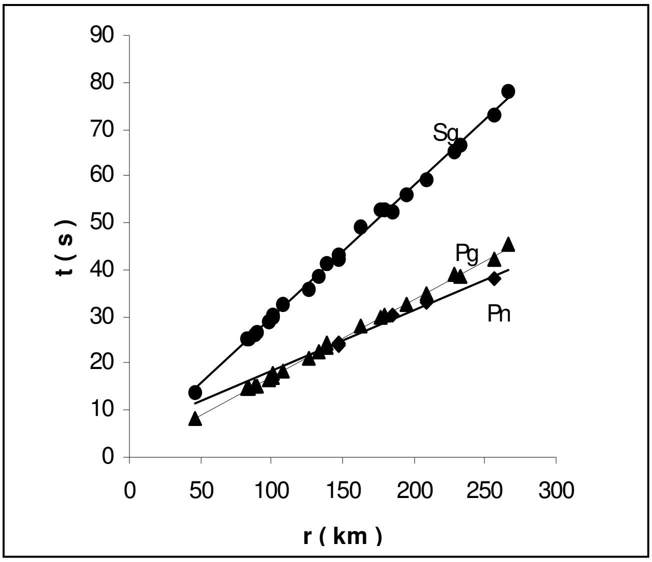

Fig.3 Travel-time curves of seismic waves Pn, Pg and Sg

One can see that at the very beginning part of travel-time curves in Fig. 3 a gap of observations is noticeable. In the near zone of explosion (up to a few kilometres) a direct wave propagating in the near-surface low-velocity layer is usually recorded. Its travel-time curve starts at the beginning and/or almost in the beginning of coordinates [0;0]. A further branch of travel-time curves corresponding to onsets far from the nearest zone of explosion usually links to the branch of direct waves. Due to the gap of data up to a distance of about 46 km, the thickness of the layer in the uppermost part of the Earth´s crust could not be determined. According to experience obtained during similar experiments performed in western Bohemia, the beginning part of the travel-time curve is very important for the inter Travel-time curves of seismic waves Pn, Pg and Sg.pretation of the velocity-depth geological profile, especially in the region of plutons. As seen in Fig. 4 in such a region, within the near zone of explosion the travel-time curve has the shape distinct from the straight-line, and therefore the approximation can be carried out using another approaches, e.g. polynomial or rational approximation. Afterwards for the determination of the velocity-depth distribution, the Wiechert-Herglotz is applicable (Novotný et al. 2004).

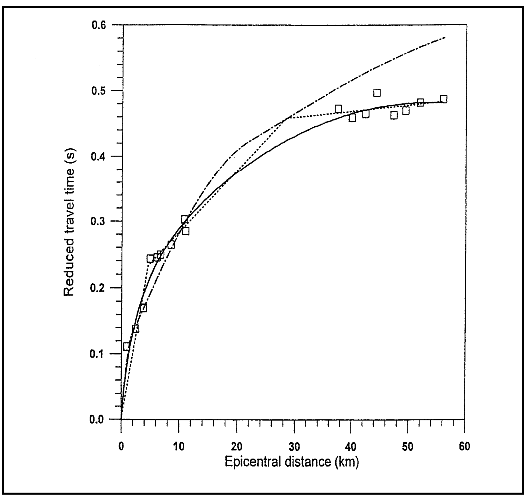

Fig.4 Approximation of P-wave reduced travel times observed along the Libá profile in western Bohemia, acc. to Novotný et al., 2004

Discussion of results

During the seismic experiment SUDETES 2003 we obtained the following results:

- the new modification of the data acquisition system PCM3-EPC2 was succesfully tested at the experimental site of observation on the refraction profile S04, which was documented by records of good quality obtained at the epicentral distance as far as 233 km (Q = 150 kg),
- simultaneously there was tested the possibility to change the triggered recording regime to the continuous one, using a remote control on the basis of implemented software,
- apparent velocities of body waves Pn, Pg and Sg were derived and were described by Eqs. (4.2) – (4.4). The values obtained during a current experiment can be compared with previous results of the investigation performed, which are given in Table 3. One can see that velocities of waves Pg and Sg are rather higher, compared with other results. The interpretation of this velocity increase suggests, on the one hand, that it is influenced by the slope of a layered medium along which the waves are propagating upwards, which causes the increase of velocity or that at larger epicentral distances the first onsets correspond to dipping refracted waves, on the other. Taking into account the directions of seismic wave propagation which were applied by Plomerová et al. (1984), Ruprechtová & Klíma (1995), Holub & Rušajová (2002) were oriented almost along parallel (E-W), while in the present research the directions of seismic waves spreading were oriented mostly along the meridian (N-S).

Tab.3 An overview of seismic wave velocities determined by various authors

Authors	Pn (km/s)	Pg (km/s)	Sn (km/s)	S* (km/s)	Sg (km/s)	v_{Pg}/v_{Sg}
Kárník (1954)	8.14	5.62	4.53	3.78	3.38	1.66
Plomerová et al. (1984)	7.82	5.65	4.17	-	3.32	1.70
Ruprechtová & Klíma (1995)	7.61	5.82	4.01	-	3.44	1.69
Holub & Rušajová (2002)	7.64	5.67	-	3.83	3.33	1.70
Růžek et al. (2004)	-	5.84	-	-	3.41	1.71
Holub et al. (current results)	7.76	6.05	-	-	3.55	1.70

The results of field experiments performed in the frame of the current grant project on the territory of northern Moravia and Silesia, where the uppermost part of the Earth´s crust is built by Lower Carboniferous sedimentary rocks. For interpretation of data, which were obtained recently, the quarry blasts, mining induced seismic events and natural microearthquake were recorded, a method of traditional tomographic iterative approach was applied for computation of a 3-D velocity model (Růžek et al., 2004). The result of these calculations for Pg waves is given in Fig. 5. The increase of seismic velocity in NW direction is obvious and corresponds also to the character of regional geological levels, especially in the area northwards from the Czech-Polish border, where crystalline rocks of the Brunovistulicum appear in deeper horizons. That interpretation relieves the idea of increasing values of the seismic velocities caused by a dipping seismic wave into a medium with a higher velocity of seismic waves.

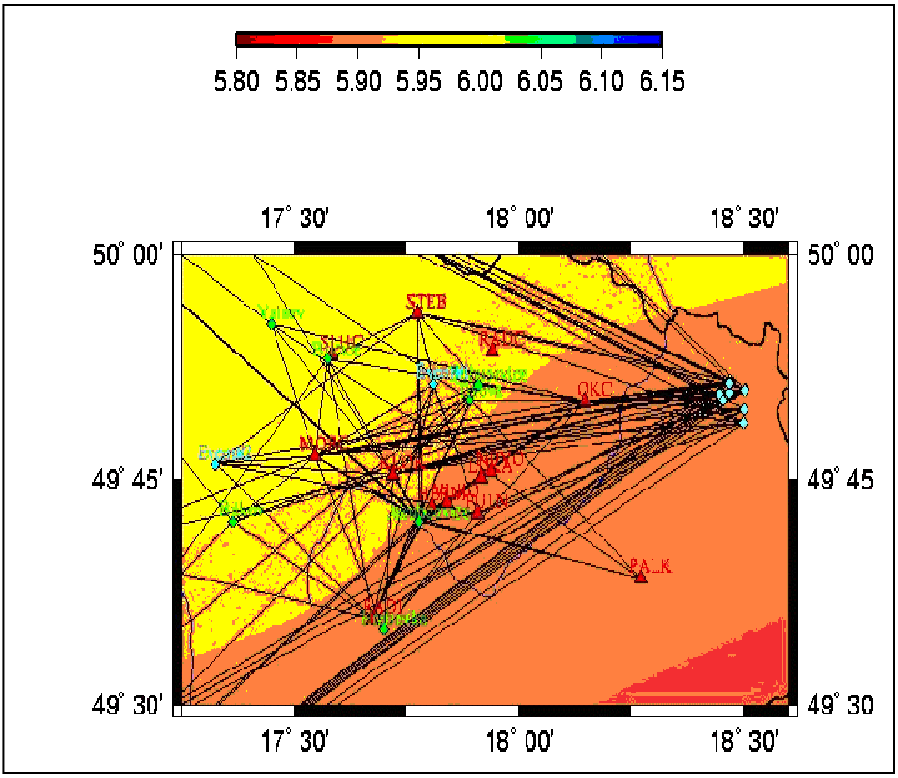

Fig.5 Resulting velocity field for dipping Pg wave, which at the depth of 5 km reaches the velocity v_{Pg} = 5.90 km/s

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