SEMIPALATINSK TEST SITE: UNDERGROUND NUCLEAR EXPLOSIONS SIGNATURES IN THE VELOCITY FIELD ON P- AND S- WAVES (FOR THE OSI PURPOSES)

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For the purposes of effective implementation of the On-Site Inspection (OSI) it is necessary to possess information on phenomenology of underground nuclear tests – on distinctive features of the explosion's impact on background geological environment and their reflections in geophysical fields. As a result of implementation of a borehole underground nuclear explosion (UNE) certain fields of rock breaking occurred in geological environment; these fields differ by their sizes and level of fracturing: camouflage cavity (radius 10÷13.6 m/kt$^{1/3}$), shear zone (up to 14÷17 m/kt$^{1/3}$), damaged zone (up to 24÷34 m/kt$^{1/3}$), high-density fissure zone (up to 50÷55 m/kt$^{1/3}$), block fractured zone (up to 65÷70 m/kt$^{1/3}$), zone of spall fractures, which occurs at epicentral distances of up to 100÷200 m/kt$^{1/3}$ and to a depth of up to 10÷32 m/kt$^{1/3}$ [Adushkin and Spivak, 2004]. Figure 1 presents a schematic view of a UNE central area immediately after the test.

One of the important aspects when using active seismic OSI technologies is the selection of a target object. The cavity and shear zone of clandestine and camouflage UNE in most of the cases will be located at a great depth, which will require using of more powerful seismic waves source. Besides, geological setting at this depth under the impact of various outer factors – gravity force, ground pressure, possible water content, etc., can significantly change in favor of solidification of underlying strata with cavity agglutination, which will hinder its detection. In this connection, as a target object of the search, it is offered to use near-surface spall zone (in red in Figure 1), which is observed for the majority of borehole UNEs.

In 1997 on the territory of Semipalatinsk Test Site (STS) in the area of UNEs seismic observations were implemented using the method of first arrivals for the purposes of studying velocity features of geological environment, which had undergone a multiple impact of borehole UNEs, and detection in the space of regional post-explosion permeable structures.

This poster presents results of seismic data complex processing for P- and S-waves calculating parameters that characterize physical and mechanical properties of background geological environment – Poisson's ratio and Vp/Vs.

Field observations and primary data processing

Seismic observations were implemented at the "Balapan" test site, which is located in the eastern part of STS, where for 25 years (from 1965 till 1989) more than 100 borehole UNEs have been carried out with the charge laying depth from 170 to 650 m under the yield from 3 to 212 kT. The system of parallel seismic profiles is located at the 6000x3500m site, the borders of which included around 15 emplacement holes. The period of carrying out underground nuclear tests is from 1972 to 1989, yield from 44 to 212 kT, their laying depth from 466 to 630m (Figure 2a).

Host geological environment at the research site is presented mainly by the rocks of sedimentary metamorphogenic rock mass of lower -medium Carbon, overlaid by Neocene clay and Quaternary alluvial sediments. In the north-eastern part of the site there are Jurassic sedimentary rocks separated from Carbon deposits by regional fault.

The observations were implemented using the method of refracted waves [Gurvich and Boganik, 1980] on profiles of 6000m long and interval between shot points (SP) of 500m and receiver points (RP) – 125m (Figure 2b). For the purposes of seismic energy injection chemical explosions with a low yield were used (with the charge mass of up to 40 kg). During the observations full-fold counter-catching-up profiling system has been applied (Figure 2c).

Recording of seismic signals has been carried out by the instrument from three-component seismic indicators SK-1P and 12-channel autonomous recording stations ASS-6/12 "Kars" (NGO "Kazgeophyspribor", USSR). Continuous recording took place onto analog magnetic tape. Inner quartz clock of the station provided reference to the absolute time with uncertainty of up to 0.01 s/day.

Figure 1. Typical configuration of the borehole UNE's central zone

Figure 2. A fragment of the topographic map of the Balapan site with highlighted research zone (a); configuration of the seismic observations (b); profiling system (c)

Figure 3 depicts an example of a seismogram of a common shot point (CSP) at the example of Pr0 SP1500. Figure 4 depicts observed travel-time curves at the example of Pr0. Values of apparent velocity were drawn on the travel-time curves (km/s), the color depicts areas with the same velocity values.

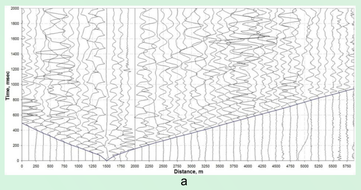

Figure 3. Example of CSP seismograms: a – for P-waves (vertical component Z, blue line – travel-time curve of P-wave); b – for S-waves (horizontal component Y, blue line – travel-time curve of P-wave, black arrows – phases of S-wave)

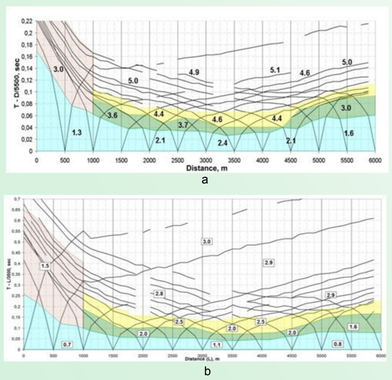

Figure 4. Observed travel-time curves systems as per Pr0 in reduced scale of time (5.5km/s for P and 3.5 km/s for S-waves): a – for P-waves, b – for S-waves.

Construction of velocity sections using forward ray tracing method

Using the constructed observed travel-time curves, a selection of velocity models in SeisWide (Dr. Deping Chian) software has been implemented, the basis of which contains an algorithm of ray tracing [Zelt and Smith, 1992]. Initial parameters of the model are the depth of cover of seismic borders, velocity and gradients of velocities of each of the given stratum. The modeling process includes selection of such parameters of the environment, a set of theoretical travel-time curves of which will best correspond to the observed times. As a result, velocity sections were constructed as per P and S waves for all 8 profiles. Using the velocity values, some parameters were calculated, which determined the physical and mechanical properties of geological environment – Poisson's ratio and Vp/Vs (Figure 5).

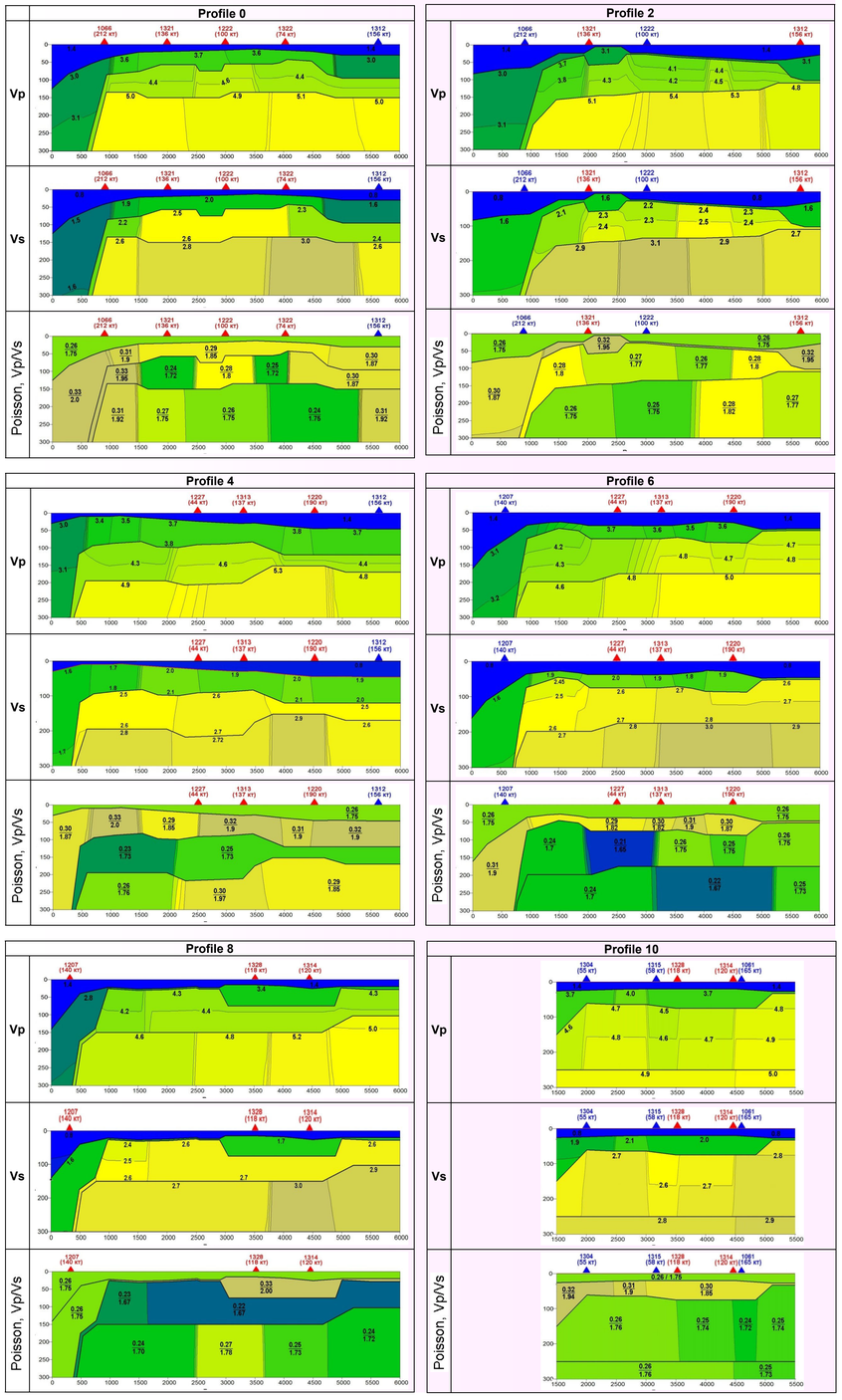

Figure 5. 2D structure sections in velocity parameters of P and S waves, elastic ratios – Poisson and Vp/Vs. Velocity profiles contain velocity values in km/s. Elastic ratio sections contain Poisson's ratio in the numerator and Vp/Vs in the denominator. The sections contain location of the emplacement holes: red color – up to 300 m normally to the profile, blue color – from 300 to 500 m, green color – more than 500 m.

Analysis of velocity sections and elastic ratios

Areas of decreased velocity values of seismic waves – up to 3.0 km/s for the P waves and up to 1.6 km/s for S-waves are observed at the velocity section in epicentral sites of UNEs at the depth from 30 to 120 m. We have interpreted these areas as spall occurrence zones (see Figure 1). Configuration of the spall zones is determined by the density of location of emplacement holes in the cross-section of the profile – for the separately located UNEs (for instance, at Pr2, Pr8 and Pr14) areas of decreased velocity values with horizontal sizes from 0.5 to 1.5 km are noted. Under more dense location of the boreholes some areas transform into a continuous low-velocity layer of up to 5km long.

Seismic results are confirmed by the geological information obtained during the boreholes drilling for nuclear explosions. According to laboratory analysis of the core sample from the depth of 40 – 80 meters (the depth of the roof of the basement unbroken by the explosion) high velocities of around 5.0 km/s for P- and 3.0 km/s for S-waves start immediately (Figure 6 a-c), which exceeds the values of modern velocity at these depths for 0.5 - 1.7 km/s. At that, for the borehole 1315, located beyond the observations site borders, but in similar geological conditions, the velocity values prior to the explosion coincide with the velocity values for the sites unbroken by the explosion, as per seismic data (Figure 6d).

Differences between initial and modern velocity values are traced until the depth mark of around 150m, after which the velocities coincide in general.

In the field of elastic parameters increased values of Poisson's ratio (up to 0.32) and Vp/Vs (up to 2.1) are noted within the limits of areas by the decreased velocity values. The increase of the mentioned ratio is characteristic for fluid-saturated porous media with increased porous pressure and enclosed hydraulic system [Puzyrev et al., 1985; Christensen, 1989; Popp and Kern, 1994]. It can be supposed that under active hydraulic regime of the pressure nature at the Balapan site [Konovalov et al., 2002] corrugated medium within the limits of spall zone is filled with underground water. At that, Neocene clay that overlay the spall areas on top, created a natural water resistance; therefore the abovementioned condition is observed.

For the rest of the sections the values of elastic ratio correspond to the general norms for the main types of geological media with natural occurrence [Spivak, 1979] – Poisson ratio is changed in the interval from 0.15 to 0.26, Vp/Vs ratio – from 1.65 to 1.78.

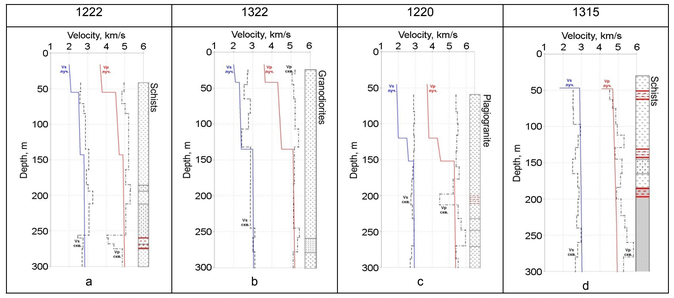

Figure 6. Comparison of the velocity regimes based on initial geological and seismic data (black dotted graphs) with the results of modern observations (red graphs for P-waves and blue for S-waves).

Conclusion

Seismic research carried out at the places of dense carrying out of underground nuclear tests allow for a range of conclusions of a productive and methodical nature, which can help in the development and modernization of the On-Site Inspections' technologies under CTBT.

The productive part of the work includes the determination of some characteristic signs of UNEs impact on the upper part of the section in terms of creation of local and regional spall structures with decreased velocity of up to 3.1 – 3.7 km/s for P-waves and 1.6 – 2.0 km/s for S-waves. These areas are also distinctly seen in the field of elastic parameters in terms of their increased values (around 0.3 – 0.32 for Poisson's ratio and 2.0 – 2.2 for Vp/Vs).

It is necessary to note that these post-explosions artifacts have a significantly long period of life and can be detected during OSI even long after the triggered event.

The methodical part of the work is in the estimate of effectiveness of the used seismic technology of refracted waves with construction of velocity profile using direct radial tracing during the detection of post-explosion artifacts.

This showed that to alleviate the task of UNE's epicenter search it is sufficient to study the section on a quite shallow depth (up to 150 m), emphasizing the target objects – spall structures in the velocity field.