Automation of seismic surveys supervision

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© **M.P. Rogachuk**
M.V. Tyshchenko
S.V. Olomskyi
Y.A. Vasylyuk
Naukanaftogaz SE of
Naftogaz of Ukraine National Joint Stock Company
S.M. Ryaboshapko
GeoSeysKontrol CJSC, Moscow
V.I. Roman
Candidate of Technical Science
N.I. Mukoyed
Subbotin Institute of Geophysics of the NAS of Ukraine

The paper presents algorithmic basics of software and hardware tools for automated supervisory control of seismic surveys within the adaptive seismic complexes.

Key words: seismic survey, supervision, noise, observation.

The response to the needs and demands of the modern seismic survey is the development and use of adaptive technology of seismic studies, as well as software and hardware for its implementation [1, 2]. The technical and technological possibilities of creation and the use of adaptive seismic survey facilities at the present stage of its development are based on the latest achievements of science and technology, including its electronic, computer and information industries. The organic kinematic and dynamic completeness of adaptive technology meets the current needs and trends of seismic studies motivated by an increase in the role and scope of detailing the structural objects and no less methodologically and technologically sophisticated exploration of non-structural geological formations. The controllability and manageability of adaptive seismic complexes with seismic record quality indicators enables the automated computer supervision of observation at the primary and basic level of technological cycle of seismic surveys, including the geological interpretation of the obtained results. The automatic adaptive supervision of observation registration and appropriate adjustments to achieve a given quality indicator of research is carried out in the course of working out the project value of observations and, in contrast to the current practice of supervision, do not result in violation of regularity and progressivity of the fieldwork.

The ultimate goal of seismic work supervision is compliance with design parameters of their quality stipulated by instructions to the customer requirements and geological problems of seismic surveys. The effectiveness of preventive design measures to ensure the quality of research is usually refuted by unpredictable and impossible proper taking into account of the spatial and temporal variability of deep and surface seismic conditions of work and unwanted seismic effects of environment. The situation is complicated by the high rate, performance of modern seismic surveys and large amounts of information received meanwhile. These circumstances lead to the lack of the existing practice of supervision of seismic surveys, based on a posteriori analysis of materials of performed works and repeated study of observations, the quality of which is proved to be not in accordance with the customer's requirements.

The key concept of adaptive technology of the seismic surveys and the basis of adaptive functioning of the seismic study complexes is a spectrum of signal-to-noise ratio, which is defined as an integral function of frequency, the value of which is the quotient of division of the target signal range module by the to noise spectrum module value for each value of frequency in the frequency range of research [2]. The requirements of geological research objectives are expressed in the form of the given spectra of signal-to-noise ratio, which in terms of seismicity regulate the temporal and amplitude resolution of research, and in geological terms – the spatial detail and parametric precision of section reproduction. During the observation based on the results of comparing the actual spectrum of signal-to-noise ratio and their set matches the adequacy of observation or the need for its continuation is determined. In the latter case, the probing signal parameters for further observation is determined and adjusted so that the desired values of the set spectra of signal-to-noise ratio were achieved. The comparison of the actually received and set spectra of signal-to-noise ratio and adjustment of observations may be multistage. The criterion for observation completion is the achievement or exceeding of the actual received spectra of signal-to-noise ratio values of their set equivalents for all target signals. The subsequent examination of the volumes of seismic studies allows adjusting the use of methodological techniques in complex surface or deep seismic geological conditions.

The availability of the criterion of optimum adjustment results and effective completion of observation volume determines the ability to create the adaptive automated quality control systems of the recorded seismic data.

Since the use of the spectra of signal-to-noise ratio is comparative in nature, it is legitimate to use their subsequent energy definition as the ratio of the square modules of signals and noise.

In essence, the signal-to-noise ratio range is the $\rho(\omega)=\frac{B_f(\omega)}{B_v(\omega)}$ spectrum of the output signal of the

optimal identifying filter of the $D(\omega)=\frac{F^*(\omega)}{B_n(\omega)}$ known arbitrary input signal $f(t)$ with spectrum $F(\omega)$ in the noise background $n(t)$,

$$\rho(\omega)=D(\omega)F(\omega)=\frac{F^*(\omega)F(\omega)}{B_n(\omega)}=\frac{|F(\omega)|^2}{B_n(\omega)}=\frac{B_f(\omega)}{B_n(\omega)}$$

where $F^*(\omega)$ – is a complex related signal spectrum $f(t)$, $B_f(\omega)$ is a spectrum of its automatic correlation function, and $f(t)$, $B_n(\omega)$ is a spectrum of the autocorrelation function of noise $n(t)$ [3]. The optimal detection filter, regardless of the intensity of the observed signal, provides the maximum r_m of the ratio between the square of the customary amplitude signal value to noise variance.

$$\rho_m=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{|F(\omega)|^2}{B_n(\omega)}d\omega=\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{B_f(\omega)}{B_n(\omega)}d\omega=\frac{1}{2\pi}\int_{-\infty}^{\infty}\rho(\omega)d\omega.$$

The integrated nature of such numerical indicator provides no basis for determining which frequency range of the noise and the extent to which it complicates the achievement of the required quality of supervision, and it does not direct the researcher towards the opposition to noise with arbitrary spectral composition with excitation of the corresponding spectral differentiated probing signals.

Such requirements are met by the signal-to-noise ratio r(ω), which, as a function of frequency, provides the spectrally differentiated adjustment of observations for the purpose of their optimization in variable seismic conditions of work, depending on the characteristics of structure and composition of the geological environment, as well as nature and intensity of noise.

The spectrum signal-to-noise ratio certainly describes the optimal Wiener's filter of reproduction of

$R(\omega)=\frac{B_s(\omega)}{B_s(\omega)+B_n(\omega)}$ signal $s(t)$ by its realizations $u(t) = s(t) + n(t)$. In turn, the optimum reproduction filter is a spectral factor of specialized optimum Wiener's filter, the generalized expression of which is defined as the correction filter $G(\omega) = R(\omega)S^{-1}(\omega)V(\omega)$, where $S^{-1}(\omega)$ is a perfect filter of signal compression $s(t)$, $V(\omega)$ is a spectrum of filter specialization signal $v(t)$, to which the observed realizations of signal $s(t)$ were brought by filter $G(\omega)$ with the minimum mean square error [3]. For the reproduction filter, in particular, $v(t) = s(t)$, $V(a) = S(G>)$; for the compression filter $v(t) = \delta(t)$, where $\delta(t)$ is a delta function, $V(\omega) = 1$.

Thus, the spectra of signal-to-noise ratio determine the algorithmic and technological ordering and orientation of the optimal observations. The optimization of observations provides for the controlled and managed comparison of the energy of excitation of informing seismic signals with the objectively existing negative factors influencing the quality of research in order to achieve its specified indices.

Above are the features of optimal adaptation of seismic studies in their spectral and temporal form. The spatial aspect of the issue is available in the case of simultaneous operation of seismic sources of their groups located in the area of works at the distances of their possible seismic mutual effects. The use of adaptive technology with the minimal impact on observations necessitates the implementation of simultaneous independent work of the grouped seismic sources by combining in time the sessions of their excitation of the probing signals with further allocation of the seismic charts of individual seismic sources of the group in the course of processing of the interference group seismic records.

The technologically feasible method of combining the sessions of simultaneous independent work of the grouped seismic groups in time is diversification of probing signal excited by them according to the scheme of Hadamard matrix elements [4].The procedure of the used Hadamard matrix must be greater than or equal to the number of concurrently operated seismic sources, and the number of excitation sessions and observation of grouped interference seismograms must be a multiple of the matrix order. The advantage of use of Hadamard matrices compared to the other features of provision of simultaneous independent operation of seismic sources is a sufficiency of manipulation with polarity of signals excited by them. The amplitude and shape of the latter may be arbitrary, but constant for the sessions of a complete technological phase of observation.

These requirements for use of Hadamard matrices are necessary and sufficient to calculate the spectra of signal-to-noise ratio on seismograms generated by each of the simultaneously working seismic sources and appropriate adjustment of the extension of observation by each of them or its completion upon reaching of the preset parameters of research quality.

In technical terms, the automation of seismic studies supervision requires the increased computing power of seismic complexes and provision of the required amount of two-way information exchange between seismic station and each of the concurrently operated seismic sources. These requirements can be met by installation of an additional computer at the seismic station and appropriate improvement of the seismic complex control system.

According to geological research objectives and methods, as well as technical equipment of field work at the time of observation, the set spectra of signal-to-noise ratio of the target signals and coding means for the probing signals of the simultaneously and independently operated seismic sources of seismic complexes (through the use of Hadamard matrices) are crucial for its implementation.

At the initial stage of observations the probing signals are excited in the frequency range provided by geological and technical problem. The initial phase is completed, if it is possible to identify the axes of target signals' in-phase operation or most intensive of them, provided that the quantitative ratios of their amplitude with the amplitude of the rest of the target signals are known. The data required to this effect for new areas can be obtained by performance of appropriate research or from the experience of testing the previous volumes in areas where the research continues.

The element of priority in processing the observed seismograms of the initial and generally any other accomplished stage of observation is allocation of seismograms generated by separate concurrently operated seismic sources and noise seismograms from grouped interferential seismic records.

Then, the actually received spectra of signal-to-noise ratios of the target signals at allocated seismograms of the concurrently operated seismic sources are computed, the calculated spectra signal-to-noise ratios is determined with their predetermined counterparts, and the spectra of spectral and energy probing signal parameters are determined based on the comparison results to continue the observation or spectral and energy indicators for its completion.

The spectrally controlled vibrating seismic sources are the most suitable for use in adaptive seismic complexes. Therefore, the subsequent presentation of the peculiarities of use of the adaptive technology for the needs of supervision of seismic surveys is carried out in terms of the vibration seismic survey.

For an unprejudiced geological analysis, the observation materials should be deprived of the technological consequences of their obtaining, just as the primary vibratory seismic seismograms are recorded in the form vibration charts and are interpreted in the form of core charts. However, the core charts are not the ultimate form of reproduction of the geological environment, not covered by the technological details, such as correlation noise. The requirements of the adaptive technology are met by the impulse seismograms obtained by deconvolution of core charts.

Despite the problems of deconvolution of noise intensification, the deconvolution positive effect is that the noises are separated with it from environmental information and can be neutralized by the corresponding spectral targeting of the probing signals excitation energy.

The calculation of the actually received spectra of signal-to-noise ratio of the target signals in accordance with an algorithm of the adaptive technology is performed after allocation of the seismograms of individual seismic sources from group seismic records in the form of vibration charts or core charts and deconvolution conversion into pulse seismograms.

The deconvolution of core charts into pulse seismograms is the most complicated and burdensome link of the computing support of the adaptive technology, especially in the case of use of the super-multi-channel observation mega-systems [5]. From the point of view of the seismic signal excitement energy minimization and sparing of energy resources it is feasible to conduct the multiple adjustmentz of parameters of the probing signals during the observation subject to calculation of the actually received spectra of signal-to-noise ratio and impulse seismograms required to that effect [2]. In this regard it is important to identify the opportunities to reduce the computation volume primarily due to reduction of deconvolution transformation of core charts into the impulse seismograms, which is achieved through definition of parameters to continue the observations or the reasons for its completion only in the critical circumstances which occur for less intense target signals at seismic records complicated with the most intense noises. For the other, less critical seismic records, the following major parameters are automatically admissible. The selection of critical seismic records is carried out according to the computational and economic algorithms, which leads to the proper functioning of adaptive seismic complexes.

Conclusion

Based on the results of comparing the actually received and set spectra of signal-to-noise ratio, the duration of observation subject to achievement of the set quality of research, which for critical seismic records may not correspond to the set productivity indicators of seismic research, is projected. In this case, the issue of possibility of withdrawal of the seismic records of some channels of the observation system from further use or the feasibility to continue the observation shall be determined in accordance with the policy guidelines.

Compared to the subjective supervision practice capable to detect only gross violations of design parameters of seismic studies, the unprejudiced computer supervision can be used in the entire range of metrological capabilities of the adaptive technology of seismic surveys, determined by the limit of economic feasibility of increase of completeness and detailed study of subsoil, until there is a positive balance of the cost of work and the value of final geological results.

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