Improving the information content of seismic data and increasing the depth of investigation by choosing the optimal length of the amplitude adjustment operator

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Abstract. The article is devoted to the role of digital automatic amplitude control in increasing the depth of seismic exploration. It is noted that the depth of productive strata is gradually increasing, at the same time, more powerful explosive sources are being replaced by relatively weak non-explosive ones. Naturally, during processing, it is necessary to pay close attention to the choice of parameters for adjusting the amplitudes. The article provides basic information about the form and amplitude of seismic vibrations, lists the main empirical formulas that characterize the dependence of the amplitudes of seismic vibrations on time. It is noted that when registering seismic vibrations, one has to deal with minimal soil displacements caused by the arrival of a seismic wave at the observation point, which must be amplified millions of times and their adjustment. In this regard, in the digital processing of seismic data, a technique was developed for recovering the true amplitudes, more precisely, the true amplitude ratio. Adjustment while maintaining the true ratio of amplitudes is used only when it is required to study the dynamics of the wave field (dynamic digital processing). The optimal choice of the length of the adjustment operator (or window) is of paramount importance, since with a small adjustment interval (less than 0.1 s), a loss of dynamic expressiveness of the recording may occur, and this is clearly shown in model studies. The article considers the efficiency of choosing the length of the optimal adjustment operator on the example of the Kurovdag area, which has complex both surface and deep seismogeological conditions. A summary of the Kurovdag field is given. An amplitude compensation function for spherical divergence is given, and to compensate for the effects associated with changes in reception and excitation conditions, a surface-matched amplitude adjustment was performed after removing amplitude bursts. A fragment of the time section is given before and after the optimal adjustment of the amplitudes according to the seismograms of the Kurovdag area, which clearly demonstrates how the information content of the time section increases and, thereby, the depth of the seismic exploration: before the optimal digital automatic adjustment of the amplitudes at times of 3.25 - 3.5 sec, no seismic horizons, while after this procedure, dynamically well-defined seismic horizons appear at the same times, reflecting the structure of the medium at great depths.

1. Introduction
An increase in the depth of research with an increase in the depth of immersion and the power of the main exploration object of Azerbaijan - the productive stratum (PS), as well as promising deposits underlying the PS on the one hand [5], the widespread use in recent decades in the practice of seismic
exploration of non-explosive sources of excitation, on the other, which, of course, are clearly inferior to explosive sources in their power, led to the need for a more careful and scrupulous attitude to adjusting the amplitudes of seismic records [10-12].

The shape and amplitude of seismic vibrations, obviously, depend not only on the power of the source, but also on a number of factors: on the properties and characteristics of excitation sources, absorbing properties of the geological environment, on the phenomena of reflection, refraction and diffraction of waves at the interfaces of elastic properties, registration features oscillations, etc. As experience shows, in the case of pulsed sources of excitation of oscillations (explosion, impact), short oscillations (pulses) arise with a small number of visible periods (two to four periods). For the analytical description of seismic vibrations as functions of time, empirical formulas are used [7].

The dependence of the amplitudes of seismic oscillations on time is expressed by various empirical formulas, among which these three often dominate:

- Proposed by G.P. Berlage and named after him by the Berlage impulse.
- Short asymmetric oscillations can be analytically represented in the form proposed by the American geophysicist N. Ricker.
- Seismic oscillations of a symmetrical form can also be expressed by a function with a bell envelope proposed by N. N. Puzyrev.

The amplitudes of seismic waves, along with the factors listed above, also depend on the distance of the receiving points, as well as on the time of their arrival at these points. The minimum soil displacements caused by the arrival of a seismic wave at the observation point are extremely small and do not exceed $10^{-6} - 10^{-7}$ mm. The minimum amplitude of oscillations that can be detected on seismic records is approximately 1–1.5 mm [7]. The dynamic range of the recording on the tracks recorded near the source is close to 90 dB. It should be noted that, first of all, the dynamic range of modern graphic representations is 24 dB. During processing, on the one hand, these signals are presented in a graphical form, on the other hand, signals recorded at different distances are processed together, on the other hand, the maximum value of the signal-to-noise ratio during processing is achieved by summing seismic traces of equal weight.

Therefore, the registration and processing of seismic data should ensure the amplification of oscillations by millions of times and their adjustment [1;7]. Such a large amplification of the recorded signals can be obtained only with the help of multistage electronic amplifiers, as well as with subsequent processing. But for this, it is first necessary to convert the mechanical displacements of the soil into electrical vibrations. Such a conversion of soil displacements caused by the arrival of a wave into electrical voltages is performed using a seismic receiver.

At present, registration of vibrations in an open channel (O/Ch) has become widespread, therefore amplification and amplitude adjustment, regardless of whether kinematic or dynamic processing is carried out, is one of the most important procedures for digital processing of seismic data.

Note that during dynamic processing, i.e. when processing in "Real Amplitudes", the relative amplitudes of seismic vibrations must be preserved [8-9].

As noted above, during the propagation of a seismic wave in a medium, its dynamic characteristics undergo significant changes due to divergence, absorption, reflection, and other phenomena [3-4]. As a result, there is a general decrease in the intensity of seismic waves with an increase in the time of their arrival, as well as a change in the intensity of the wave recorded at different points of the observation profile. At an early stage of digital processing, seismic surveys were used primarily for solving structural problems. To do this, it was enough to restrict ourselves to tracing the so-called reference waves, which was provided by the procedures for filtering and amplifying weak signals. Changes in the intensity of the signals (true amplitudes) were deliberately eliminated in order to improve the visual expressiveness of the reflections. At present, when the high geological information content of the dynamic characteristics of seismic waves (true amplitudes, frequencies, etc.) has been established, such a simplified approach is no longer enough. In this regard, in the digital processing of
seismic data, a technique was developed for recovering the true amplitudes, more precisely, the true amplitude ratio.

*Automatic amplitude control (AAC).* Adjustment while maintaining the true ratio of amplitudes is used only when it is required to study the dynamics of the wave field (dynamic digital processing). In cases where processing is carried out without preserving the true amplitudes, AAC is used.

Quite often, field records of seismic vibrations in terms of the average level of visible amplitudes differ greatly on different traces, as if they were recorded at different sensitivities of seismic recording channels [11]. Before summing up the records according to CMP (CDP), it is necessary to equalize the levels (amplitudes) of the summed records. It is known that equalization is performed by multiplying the instantaneous values of the amplitudes \( A(t) \) by the correction factor \( q(t) \) (adjustment operator), which is constant within a given "time window" (interval) \( T \) of the trace (digital AAC). The adjustment process consists in normalizing the reference amplitudes \( A(tj) \) by coefficients \( q(t) \) inversely proportional to the actual recording intensity on a given trace.

The optimal choice of the length of the adjustment operator (or window) is of paramount importance, since with a small adjustment interval (less than 0.1 s), a loss of dynamic expressiveness of the recording may occur, i.e., dynamic differences between the recordings of reflected waves from different boundaries are erased; as the window length increases, the dynamic distortions of seismic records decrease (figure 1).

![Figure 1](image_url)

*Figure 1.* Influence of record adjustment operator length on its dynamic expressiveness: a – initial synthetic seismic record; b – operator length 100 ms; c - operator 40 ms long.
2. Materials and methods

Now let's consider the efficiency of choosing the length of the optimal adjustment operator using the example of the Kurovdag area, which has complex both surface and deep seismogeological conditions.

Tectonically, the Kurovdag deposit is located in the Nizhnecurinskaya depression in the Shirvan steppe of Azerbaijan, 120 km southwest of Baku [6]. The field is part of the Kura-South-Caspian oil and gas province (figure 2). The tectonic belt of southeastern Shirvan includes four anticlinal zones: Pirsagat-Khamamdag; Harami-Mishovdag-Kalmas-Khydyrly-Agaevir-Bandovan; Kursangya; Padar-Kyurovdag-Karabagly-Babazanan-Duzdag-Neftechala.

![Tectonic bands of southeastern Shirvan.](image-url)

Figure 2. Tectonic bands of southeastern Shirvan.
The commercial oil and gas potential of the field was established on July 18, 1955 during the testing of exploration well No. 2, which gave a fountain of oil from a depth of 1930 m, corresponding to the PS01 horizon of the deposits of the Pliocene productive strata of the main oil and gas bearing strata of Azerbaijan.

The first seismic work in this area was carried out in the second half of the 40s of the 20th century, in 1946-1948. Single seismic profiles of 2D single-overlapped SW were worked out. So in 1948, 5 profiles with a length of 30 linear meters were worked out. km. In 1956, seismic surveys were carried out and CMPV with a volume of 80 linear meters. km, which made it possible to clarify and detail the system of longitudinal disturbances. In 1958, seismic surveys of the MOV and KMPV in the amount of 100 linear meters. km were carried out mainly in the northwestern periclinal part of the structure.

In 1975, three profiles with a length of 25 lin. km. In 1984-1987. 10-15 linear meters were worked out annually. km of CDP profiles in the north-east of the structure to identify elements of the junction of the Kurovdag area field with the Mishovdag structure.

VSP work on the study area was carried out for the first time in 2002 by the "PetroAlliance" Company in four wells (408, 598, 920, 1022). The section with these wells was studied up to the PS07 horizon (inclusive) of the productive stratum.

In 2002-2003 3D CDP seismic work was carried out within the Kurovdag field. The area of work was 265 km² (which corresponds to 20,000 physical observations). At the field, 3D seismic data were reinterpreted in 2021 at the Department of Geophysics of the Azerbaijan State University of Oil and Industry.

Within the Kurovdag deposit, the sedimentary complex at accessible depths is represented by post-Pliocene and Pliocene deposits of the Cenozoic era. Deposits of the productive strata, in which the main oil and gas objects are concentrated, have been opened by a large number of deep exploration and production wells. The range of variation in the depths of the top of the sequence is from −927 m (borehole 957 in the southeast) to −3496 m (borehole 407 in the north). The maximum thickness of the productive stratum was discovered by deep exploratory well 425, at a bottomhole of 5190 m it is 3354 m. In the remaining wells, the exposed part of the productive stratum is much smaller and averages 700-800 m. The productive stratum is represented by alternating sand and clay formations of various thicknesses.

3. Results and Discussion
The processing of seismic data after routine standard procedures began, of course, with the stage of amplitude adjustment, which is of particular importance for the study area due to the increase in the depth of the main oil and gas bearing objects in the lower productive strata [8-9].

Compensation for the spherical divergence of the wave front. To compensate for the amplitudes for the spherical discrepancy, a function was applied (figure 3). The choice of the exponential is due to the fact that multiplication by this function compensates for the decrease in the energy of seismic waves associated with absorption and spherical divergence.
Surface-matched amplitude adjustment. To compensate for the effects associated with changes in the reception and excitation conditions, a surface-matched adjustment of the amplitudes was performed after the removal of amplitude bursts. Coefficients for surface-matched adjustment were calculated in the window described in table 1.

Table 1. Computation window for surface-matched amplitude adjustment.

| OFFSET | TIME START, ms | TIME END, ms |
|--------|----------------|--------------|
| 0      | 200            | 4500         |
| 4500   | 2500           | 5000         |

Calculation factors: source / destination / removal. Application factors: source/sink. Surface-matched amplitude factors were obtained and introduced into seismograms (figure 4).

Figure 3. PV 504. A fragment of a seismogram before (a) and after (b) the restoration of amplitudes for spherical divergence.

Figure 4. Coefficients for surface-consistent adjustment a) according to the SP, b) according to the PP Kyurovdag area.
Harmonization of deletions in the unit cell of accumulation (bin). The goal of regularization was to ensure that the distribution of traces subject to pre-stack migration was uniform within the equidistance panels. The regularization was carried out in two stages: the creation of a regular system of accumulation points (binning) and interpolation to improve the distribution of traces of different offsets within one bin. The binning was performed by panels of equal offsets, i.e. with the division of all traces into groups with the same range of distances from the point of explosion to the point of reception, and the technique itself consisted in borrowing the missing traces from neighboring offset panels. Borrowing was carried out within a given radius. As a result of binning, the maximum filling of the gaps in the panels of equal offsets was achieved to optimize the conditions for subsequent interpolation over sets of equal offsets [2]. As a result of testing, the following parameters were chosen that allow optimal binning and, in general, data regularization without loss of material quality: search radius during binning - 30 m; binning spacing step - 50 m.

The second stage of data regularization was carried out on CDP sets by interpolation between traces to fill in the missing bins. On the basis of the tests carried out, the following were selected and applied for interpolation: offset step - 50 m; interpolation base - 100 m.

During the harmonization process, additional noise suppression procedures were carried out (figure 5).

![Figure 5. A fragment of the time section a) before and b) after the optimal adjustment of the amplitudes according to the seismograms of the Kurovdag area.](image)

4. Conclusion

The above example clearly demonstrates how the information content of the time section and, thereby, the depth of the seismic survey increase. Before the optimal digital automatic adjustment of the amplitudes, no seismic horizons are observed at times of 3.25 - 3.5 seconds, while after this procedure, dynamically well-defined seismic horizons appear at the same times, carrying valuable information about the structure of the section at these rather large, depths.
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