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GEOFIZIKAI KÖZLEMÉNYEK
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The effect of dip of the reflecting boundary on the stacking of common-depth-point channels

T. BODOKY*

In seismic exploration, the aim of applying common-depth-point systems is the suppression of random noises and multiple reflexions. The filtering of random noises is based upon the statistical filtering effect of stacking independently recorded channels; the filtering-out of multiples, however, is determined by transfer functions derivable also in a deterministic way.

The filtering effect of common-depth-point systems on multiples was discussed in detail in a previous paper by the author (BODOKY, 1970), where the following relation has been established for the multiply reflected energy, resp. for its attenuation produced by the stacking channel type given:

$$\Phi(t_0, d) = \frac{\int_0^\infty [A(\omega) S(\omega, t_0, d)]^2 \, d\omega}{\int_0^\infty [n A(\omega)]^2 \, d\omega} \tag{1}$$

where

Φ	the ratio of attenuated and unattenuated multiple energy
t_0	arrival time
d	seismometer spacing
ω	circular frequency
$A(\omega)$	spectrum of the arrival
$S(\omega, t_0, d)$	the transfer function of the stacking channel in question
n	stacking number

The form of the transfer function $S(\omega, t_0, d)$ is

$$S(\omega, t_0, d) = \sum_{i=1}^{n} e^{j\omega\tau_i(t_0, d)} \tag{2}$$

where

$\tau_i(t_0, d)$ the value of the "residual moveout" belonging to the i-eth channel to be stacked, on the place (t_0, d).

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* Roland Eötvös Geophysical Institute, Budapest.

The value of the residual moveout on a given channel is the difference between the moveouts of the multiple arrival related to the same t_0, resp. of the primary arrival:

$$\tau(t_0, d) = \delta \Delta t(t_0, d) = \Delta t_T(t_0, d) - \Delta t(t_0, d) \tag{3}$$

where

$\delta \Delta t$ the residual moveout
Δt_T the moveout of the multiple arrival
Δt the moveout of the primary arrival

In principle, the value of geometrical correction agrees with the moveout of the primary arrival; consequently the right-hand side of the relation (3) may be considered as the difference of the moveout of any arrival and of the value of geometrical correction. From this interpretation of (3) it is clear that the primary arrivals are stacked with mutual reinforcement and in right phase, the multiples, however, with a phase difference of $\delta \Delta t$, mutually attenuating each other.

The value of geometrical correction is computed under the assumption of horizontal reflecting planes, consequently Δt signifies the moveout of a reflexion from a horizontal boundary.

In the majority of cases, however, the reflecting boundaries are not horizontal, but dipping. Therefore it is in place to examine the question, what effect has the dip on stacking. The investigation will be carried out both for primary arrivals and multiples.

Primary arrivals from dipping boundaries

According to Cressman (1968), if the dip angle in profile direction is α then

$$\Delta t(\alpha) = \Delta t \cos^2 \alpha \tag{4}$$

where $\Delta t(\alpha)$ is the value of the moveout of a primary arrival from a boundary dipping at an angle of α.

If this is substituted in (3), as the actual moveout of a primary arrival, also primary arrivals from a dipping boundary have their residual moveouts,

$$\delta \Delta t(\alpha) = \Delta t \cos^2 \alpha - \Delta t = -\Delta t \sin^2 \alpha. \tag{5}$$

In case of dipping reflectors, then, the phase-difference-free stacking of simple primaries will not be fulfilled.

In order to investigate the effect of dip-caused phase-difference also numerically, let us substitute relation (5) in the transfer function of (2), resp. in formula (1). The relation established in this way permits the computation of the attenuation function of three variables $\Phi(t_0, \alpha, d)$. For illustrativeness sake let us compute functions $\Phi(t_0, \alpha)$, resp. $\Phi(\alpha, d)$ keeping one of the variables fixed.

According to the points of view of the paper mentioned in the beginning, let us choose the stacking-channel types, denoting them, in the way mentioned there, with a series of shotpoint-distances, of the channels figuring there, given in seismometer spacing units.

The stacking-channel types selected are:

the (1.5 2.5 5.5 6.5 9.5 10.5) type stacking channel of the split-spread system,
the (12 16 20 24 28 32) type stacking channel of the offset shotpoint system.

With these selected stacking-channel types the attenuation function computations $\Phi(t_0, \alpha, d)$ were carried out with the spectrum and velocity function used also in the paper mentioned in the introduction, according to the formulas (5), (2) and (1).

In the following, the value of the Φ functions will always be given in decibels.

The $\Phi(\alpha, d)$ functions obtained for $t_0 = 2$ sec are visible, in a sequence corresponding to the enumeration of channel types, in the first two figures (Fig. 1–2).

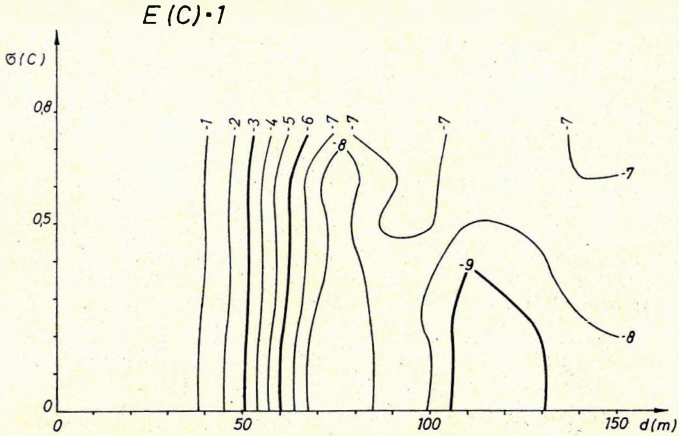

Fig. 1 The $\Phi(\alpha, d)$ attenuation function of the (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) stack channel type, calculated for primary reflexions (represented in dB; d = seismometer-spacing; α = dip-angle)

1. ábra. az (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) összegcsatorna típus $\Phi(\alpha, d)$ csillapítási függvénye egyszeres reflexiókra számítva (dB-ben ábrázolva; d = geofonköz; α = dőlésszög)

Рис. 1. Функция затухания $\Phi(\alpha, d)$ суммотрассы типа (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) для однократных отражений (в дб; d — шаг сейсмоприемников; α — угол наклона)

An examination of these figures shows that the attenuation of primary arrivals, caused by the dipping of the reflecting boundaries, determines, for a given stacking-channel type, the maximum permitted seismometer spacing, and the maximum permitted seismometer spacing decreases with the increase of both the dip and the distance of recording.

Figs. 3 and 4 present the $\Phi(t_0, \alpha)$ functions of the same channel types. The seismometer spacing is fixed at the multiple-suppression optimum of the individual channels, i.e. $d = 110$ and $d = 50$, in turn.

According to these figures, our statements can be completed by the following:

— at low t_0 values, especially with such large seismometer spacing, the primary arrivals are very sensitive against dip. With an increase of t_0, this sensitivity rapidly decreases, and the cut-off zone rapidly shifts towards greater dips.

— if the seismometer spacing is selected for an optimum as to multiple-suppression, the place of the cut-off-zone is practically independent of recording distance;

— the steepness of cut-off and the value of maximum attenuation increases with an increasing recording distance.

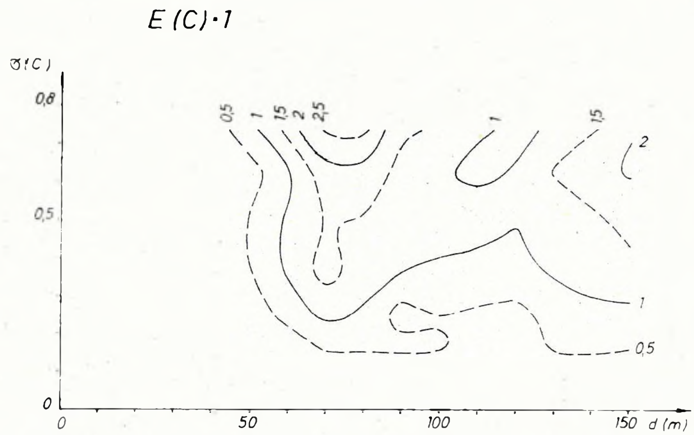

Fig. 2 The $\Phi(\alpha, d)$ attenuation function of the (12, 16, 20, 24, 28, 32) stack channel type, calculated for primary reflexions (represented in dB; d = seismometer-spacing; α = dipangle)

2. ábra. A (12, 16, 20, 24, 28, 32) összegcsatorna típus $\Phi(\alpha, d)$ csillapítási függvénye egyszeres reflexiókra számítva (dB-ben ábrázolva; d = geofonköz; α = dőlésszög)

Рис. 2. **Функция затухания $\Phi(\alpha, d)$ суммотрассы типа (12, 16, 20, 25, 28, 32) для однократных отражений (в дб; d — шаг сейсмоприемников; α — угол наклона)**

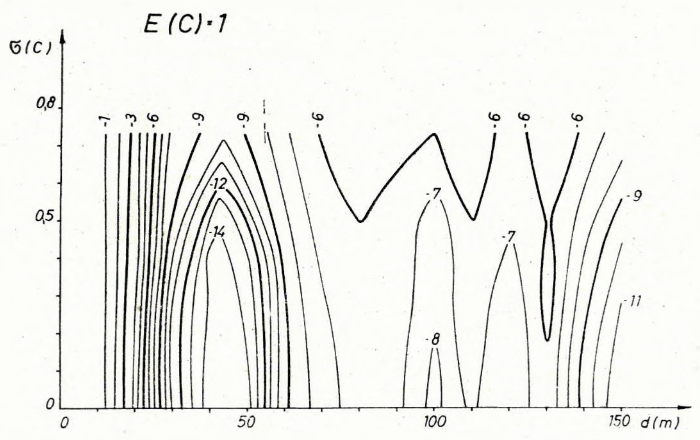

Fig. 3 The $\Phi(t_0, \alpha)$ attenuation functionfo the (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) stack channel type, calculated for primary reflexions (represented in dB; α = dip-angle; seismometer spacing = 110 m)

3. ábra. Az (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) összegcsatorna típus $\Phi(t_0, \alpha)$ scillapítási függvénye egyszeres reflexiókra számítva (dB-ben ábrázolva; α = dőlésszög; geofonköz 110 m)

Рис. 3. **Функция затухания $\Phi(t_0, \alpha)$ суммотрассы типа (1,5; 2,5; 5,5; 6.5; 9,5; 10,5) для однократных отражений (в дб; α — угол наклона; шаг сейсмоприемников — 110 м)**

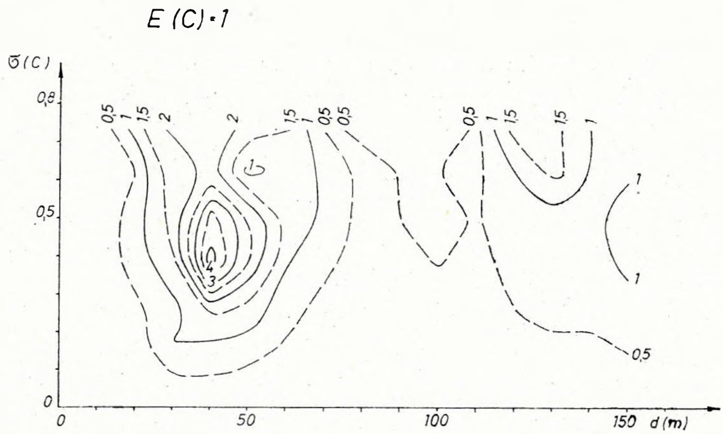

Fig. 4 The $\Phi(t_0, \alpha)$ attenuation function of the (12, 16, 20, 24, 28, 32) stack channel type, calculated for primary reflexions (represented in dB; α = dip-angle; seismometerspacing: 50 m)

4. ábra. A (12, 16, 20, 24, 28, 32) összegcsatorna típus $\Phi(t_0, \alpha)$ csillapítási függvénye egyszeres reflexiókra számítva (dB-ben ábrázolva; α = dőlésszög; geofonköz 50 m)

Рис. 4. Функция затухания $\Phi(t_0, \alpha)$ суммотрассы типа (12, 16, 20, 24, 28, 32) для однократных отражений (в дб; α — угол наклона; шаг сейсмоприемников — 50 м)

Dipping boundaries and multiple reflexions

Next, the effect of dip upon the multiple attenuation of individual stacking channels will be discussed.

If merely the simplest, i.e. double-way multiple reflexion is considered, this behaves, according to the laws of geometrical optics, as a primary reflexion from a boundary dipping at 2α.

Its moveout is:

$$\Delta t_T(\alpha) = \Delta t_T \cos^2 (2\alpha).$$

Hence, the residual moveout:

$$\delta \Delta t(\alpha) = \Delta t_T \cos^2 (2\alpha) - \Delta t. \tag{6}$$

The expression of $\delta \Delta t(\alpha)$ will be substituted in (2), further the obtained function $S(\omega, \alpha, t_0, d)$ in formula (1). With the formula obtained in this way, the attenuation function $\Phi(t_0, \alpha, d)$ is computed also for the multiple reflexion.

The $\Phi(\alpha, d)$ functions of the two stacking channels figuring also in the previous computations are presented in the figures 5 and 6 in due order, calculated for multiples at $t_0 = 2$ sec. In the next two figures, again, (7 and 8), the $\Phi(t_0, \alpha)$ functions of the same channel types are visible, with the calculation of seismometer spacing as optimum for multiple-suppression, i.e. for $d = 110$ m and $d = 50$ m, in due order.

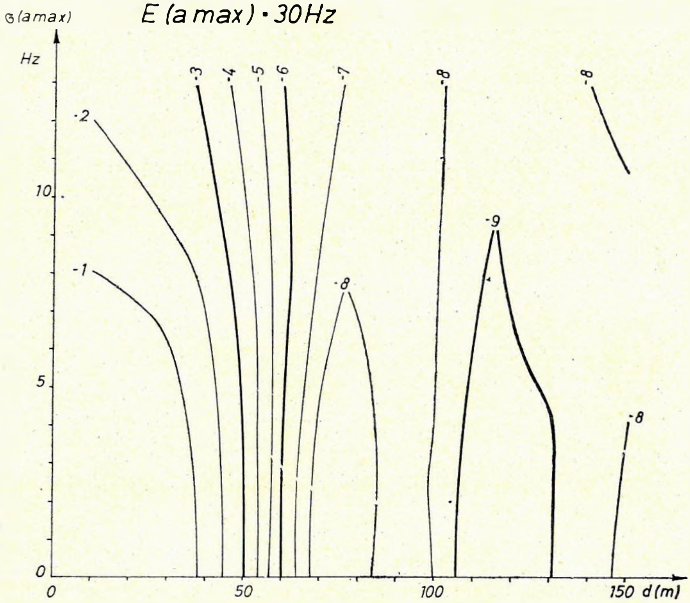

Fig. 5 The Φ (α, d) attenuation function of the (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) stack channel type, calculated for primary reflexions (represented in dB; $d=$ seismometer-spacing; $\alpha=$dip-angle)

5. ábra. Az (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) összegcsatorna típus $\Phi(\alpha, d)$ csillapítási függvénye többszörös reflexiókra számítva (dB-ben ábrázolva; $d=$geofonköz; $\alpha=$dőlésszög)

Рис. 5. Функция затухания $\Phi(\alpha, d)$ суммотрассы типа (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) для кратных; отражений (в дб; d — шаг сейсмоприемников; α — угол наклона)

It is visible from the figures that

— the value of multiple-attenuation, as expectable according to (6), decreases on account of the dip of the reflecting boundary, becoming zero at a critical dip value. With a further increase of the dip, it starts to improve again.

— The place of the zone with zero attenuation depends on recording time only. It does not depend on either seismometer spacing or offset value, consequently no means are given to influence it.

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The results presented throw up two problems

One of them is: how to solve, in case of a dipping boundary, the stacking of simple reflections without phase-difference? The other: what can be done, in this case, against multiples?

The stacking of primary reflexions without phase-difference is ensured, if the value of geometrical correction is, instead of Δt, $\Delta t \cos^2 \alpha$. For this, however, the accurate position of the reflecting boundaries must be known in advance, but exactly this is the aim of the measurement. This contradiction is circumvented by up-to-date computer procedures in such a way that they determine the value of the geometrical correction in an empirical way from the measurement materials. This operation, the "velocity-analysis", must be made with a "sampling rate" according to the geological build-up of the area under investigation, since the value of corrections depend on the geological structure through dip conditions, and thus the results of one or two analyses cannot always be extended to the entire section.

The suppression of multiples is the harder one of the two tasks. Applying the proper geometrical correction, the value of the residual moveout will be

$$\delta\Delta t = \Delta t_T \cos^2 (2\alpha_1) - \Delta t \cos^2 \alpha_2$$

where α_1 — the dip of the boundary reflecting multiples,
α_2 — the dip of the boundary reflecting primaries.

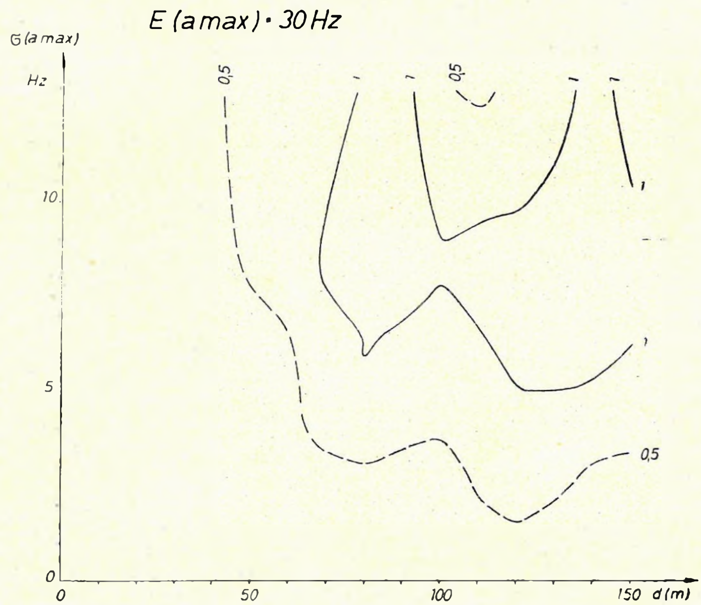

Fig. 6 The $\Phi(\alpha, d)$ attenuation function of the (12, 16, 20, 24, 28, 32) stack channel type, calculated for primary reflexions (represented in dB; d = seismometer-spacing; α = dip-angle)

6. ábra. A (12, 16, 20, 24, 28, 32) összegcsatorna típus $\Phi(\alpha, d)$ csillapítási függvénye többszörös reflexiókra számítva (dB-ben ábrázolva; d = geofonköz; α = dőlésszög)

Рис. 6. Функция затухания $\Phi(\alpha, d)$ суммотрассы типа (12, 16, 20, 24, 28, 32) для кратных отражений (в дб; d — шаг сейсмоприемников; α — угол наклона)

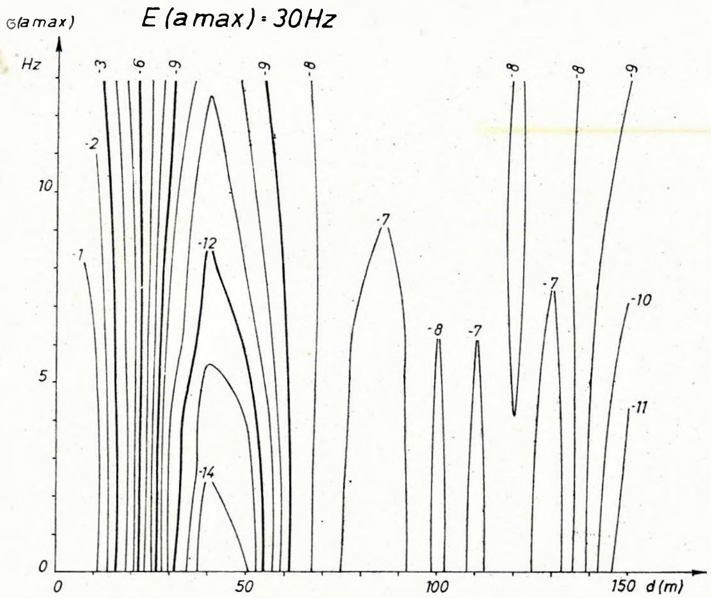

Fig. 7 The $\Phi(t_0, \alpha)$ attenuation function of the (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) stack channel type, calculated for multiple reflexions (represented in dB; α = dip-angle)

7. ábra. Az (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) összegcsatorna típus $\Phi(t_0, \alpha)$ csillapítási függvénye többszörös reflexiókra számítva (dB-ben ábrázolva; α = dőlésszög)

Рис. 7. Функция затухания $\Phi(t_0, \alpha)$ для суммотрассы типа (1,5; 2,5; 5,5; 6,5; 9,5; 10,5) для кратных отражений (в дб; α — угол наклона)

Since no necessary relation exists between α_1 and α_2, the possibility of the following case may always exist:

$$\Delta t_T \cos^2 (2\alpha_1) \approx \Delta t \cos^2 \alpha_2$$

that is,

$$\delta \Delta t \approx 0$$

meaning zero multiple-attenuation.

With up-to-date computer procedures, with the computer modelling of actual wave-paths, this problem, too, can be solved, according to literary data. In our home practice, however, for the time being this is not yet possible, consequently this eventuality must be taken into account.

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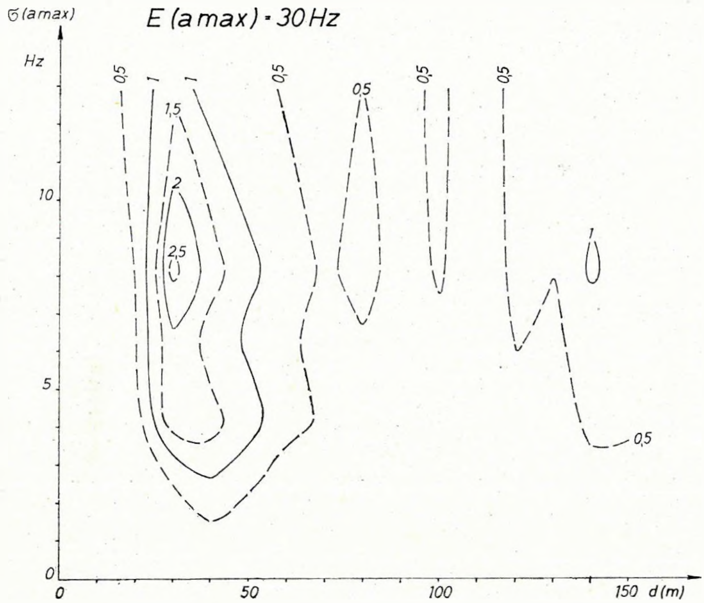

Fig. 8 The $\Phi(t_0, \alpha)$ attenuation function of the (12, 16, 20, 24, 28, 32) stack channel type, calculated for multiple reflexions (represented in dB; α = dip-angle)

8. ábra. A (12, 16, 20, 24, 28, 32) összegcsatorna típus $\Phi(t_0, \alpha)$ csillapítási függvénye többszörös reflexióra számítva (dB-ben ábrázolva; α = dőlésszög)

Рис. 8. Функция затухания $\Phi(t_0, \alpha)$ для суммотрассы типа (12, 16, 20, 24, 28, 32) для кратных отражений (в дб; α — угол наклона)

BODOKY TAMÁS

A VISSZAVERŐ FELÜLET DŐLÉSÉNEK HATÁSA A KÖZÖS MÉLYSÉGPONTOS CSATORNÁK ÖSSZEGEZÉSÉNÉL

A tanulmány a reflektáló felületelemek dőlésének a közös mélységpontos összegezés végrehajtásakor fellépő hatását vizsgálja. Két különböző offsetű összegcsatorna típusra kiszámítja az összegezés átviteli függvényét a terjedési idő és a dőlés, illetve a dőlés és a geofontávolság függvényében. A számításokat mind egyszeres, mind többszörös reflexiókra elvégzi.

A számítások eredményeként megállapítható, hogy az egyszeres beérkezéseknek a dőlés következtében fellépő csillapítása felső határt szab a geofontávolságok hosszának. Mind a dőlés, mind az offsett növekedtével ez a felső határérték csökken.

A kis beérkezési idejű egyszeres reflexiók igen érzékenyek a dőlésre, a beérkezési idő növekedtével az érzékenység rohamosan csökken.

A többszörös reflexió-csillapítás a dőlés következtében csökken, egy kritikus értéknél zérussá válik, majd ismét növekedni kezd.

A zérus kioltással jelentkező zóna helye csak a terjedési időtől függ, a terjedési idő növekedtével ez a zóna a nagyobb geofontávolságok felé tolódik.

Т. БОДОКИ

О ВЛИЯНИИ НАКЛОНА ОТРАЖАЮЩЕЙ ПОВЕРХНОСТИ ПРИ СУММИРОВАНИИ ЗАПИСЕЙ ПО МЕТОДУ ОГТ

В работе анализируется влияние наклона отражающих площадок, наблюдаемое при суммировании записей по методу ОГТ. Для двух типов суммотрасс, при различной степени смещения пункта возбуждения вычисляются характеристики в зависимости, соответственно, от времени пробега и углов наклона, а также от углов наклона и шага сейсмоприемников. Вычисления проводятся как для однократных, так и для многократных отражений.

Результаты вычислений показывают, что затуханием однократных волн, связанным с наклоном поверхности, обусловливается максимальный шаг сейсмоприемников. С увеличением как углов наклона, так и степени смещения пункта возбуждения, уменьшается верхний предел шага сейсмоприемников.

Однократные отражения с небольшими временами вступления весьма чувствительны к наклонам, причем с возрастанием времени эта чувствительность резко снижается.

Затухание кратных отражений уменьшается с увеличением углов наклона; при определенной критической величине последнего оно становится равным нулю, а затем снова увеличивается.

Место зоны с нулевым затуханием зависит только от времени пробега; с увеличением последнего эта зона смещается в сторону больших шагов сейсмоприемников.