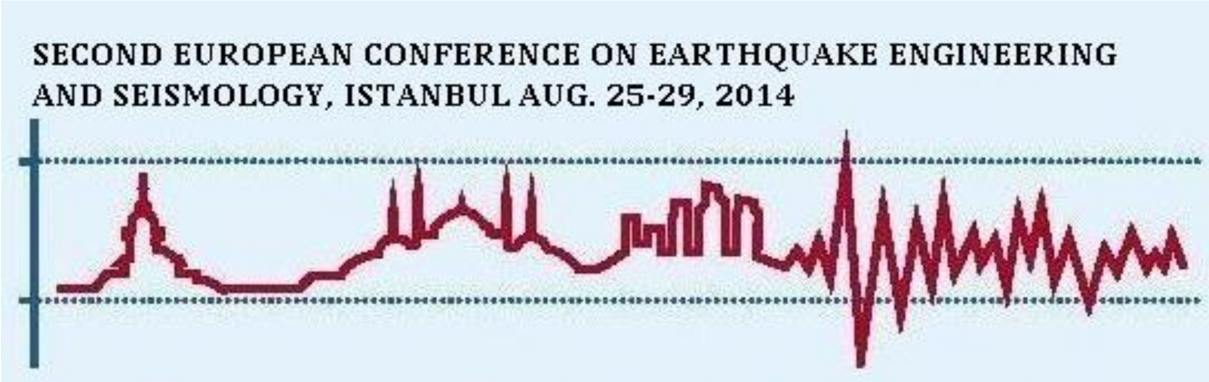

EXPERIENCE OF LINEAR STRUCTURES MICROZONATION IN SOUTHERN YAKUTIA WITHIN CRYOLITHOZONE

Evgenii BRYZHAK[1], Vasilii DZHURIK[2], Sergei SEREBRENNIKOV[3], Artem SHAGUN[4]

ABSTRACT

We consider experimental and computational methods and their ability to improve engineering seismological forecast during the construction of linear structures within cryolithozone. Approach of using probabilistic experimental frequency characteristics for calculating accelerograms of strong earthquakes with parameters corresponding to area initial seismicity requires further improvement. It can be considered as a variant of a best approximation to use microseisms in different soil condition for seismic hazard assessment in the parameters of seismic effects, if they are considered under the assumption of direct feedback amplitudes and strength characteristics of soils. It is important that such a pattern corresponds to seismic hazard assessment for its direct amplitude-frequency seismic zoning method, based on the registration of close earthquakes.

Key indicators of seismic hazard, obtained according to theoretical calculations, can be brought into line with the experimental data for each soil condition when the soil will be justified their seismic model, designed and scaled for each of these parameters of seismic effects corresponding to the initial seismicity. In this case, the calculations for each state of the soils (water-unsaturated, water-saturated and frozen) would be the most reasonable and comply with the experimental measurements. The latter are the basis for predicting the parameters of seismic effects in the event of partial or complete degradation of permafrost as a result of construction.

Basis for accelerograms spectra acceleration and frequency characteristics were the results of computational and instrumental methods of seismic zoning (seismic rigidities and microseisms). The result is a set of necessary data to assess the seismic engineering construction conditions of the line structure, located in the nine intensity seismic zone and in complex permafrost conditions.

With sufficient statistical seismic zoning characteristics set, recorded using instrumental methods, the calculating of the initial seismic signal with the main parameters of earthquake source zones, corresponding to the initial seismicity of construction, and data records of local earthquakes, it provides the necessary set of parameters of seismic effects, taking into account for the design of permafrost degradation aseismic linear structures.

INTRODUCTION

Experience of the engineering and seismological researches conducted in the Baikal seismic zone, in the presence of permafrost, showed that the technique of calculations of seismic effects for the main

[1] Chief engineer, Institute of the Earth’s crust, Irkutsk, bryzhak@crust.irk.ru
[2] Doctor of Geology and Mineralogy, chief research scientist, Institute of the Earth’s crust, Irkutsk, dzhurik@crust.irk.ru
[3] Ph. D in Geology and Mineralogy, senior research scientist, Institute of the Earth’s crust, Irkutsk, serebr@crust.irk.ru
[4] Junior Research Scientist, Institute of the Earth’s crust, Irkutsk, shagun@crust.irk.ru

conditions of soil (frozen, melted water-unsaturated and water-saturated) is rather proved [Site effect assessment, 1988], but the assessment of the maximum accelerations and spectrum in case of large earthquakes demands improvement. Realization of one of such opportunities we give on the example of justification of seismic hazard of linear constructions (the South of Yakutia) of the planned 180 km railway line "Ikabyekan station-Tarynnakhsky mining" (Fig. 1).

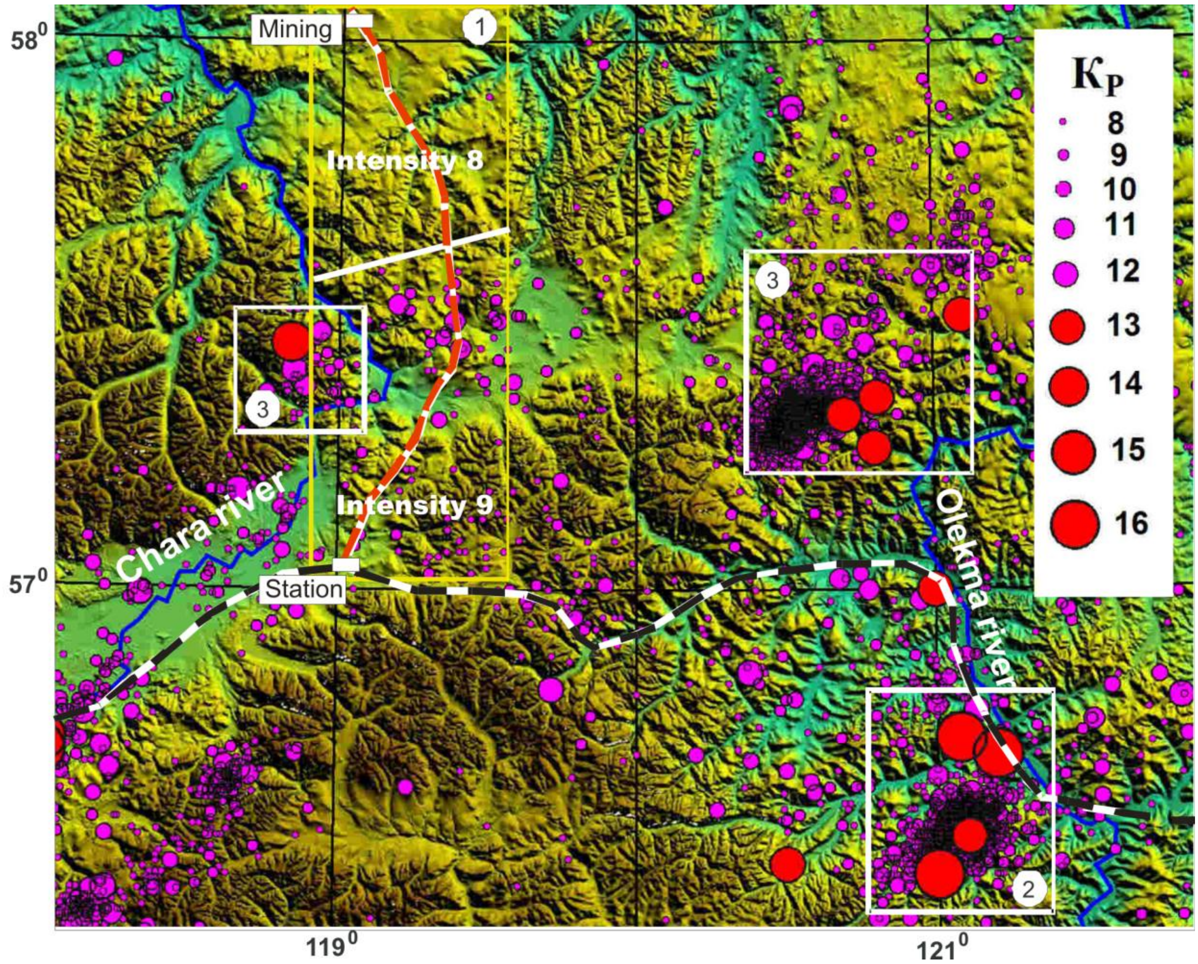

Figure 1. Review map of seismicity of the region. Кр – energy class of earthquakes (up to 2010) from 8 to 16; 1 – area of construction; 2 – zone of Tas-Yuryakhsk (1967) earthquake, Olekma earthquake (1968) and Nyukzhin (1958) earthquake; 3 – zones with relatively increased density of earthquake sources.

Construction of the railroad is connected with planning of complex development of the region, first of all it includes construction of various industrial facilities located in areas with high seismicity that poses serious problems of ensuring seismic safety of such objects and especially linear constructions. On the review map of seismicity (Fig. 1) the region of South Yakutia, that repeatedly was influenced by earthquakes with intensity 7-9, is presented.

On the whole the studied area is included in the zone of entire and insular distribution of permafrost soils. The thickness of frozen layer varies between 0 and 300 m, temperature of frozen soil fluctuates between 0,5-1,0 and 3-5 °C under zero [Geocryological map of Russian territory, 1996]. It is also confirmed by data of direct measurements of temperature during engineering-geological researches conducted for construction justification. The zone of intensity 9 is in rather more severe climatic conditions and therefore the northern part of the route is characterized by big distribution in the basis of the constructions of melted soils.

The assessment of the maximum accelerations for the route and for sites of bridge constructions are carried out for intensity 9 (southern) and 8 (northern) parts of route (Fig. 1). The brief seismogeological data given in figure 1 were used for forming of the initial seismic signal. It was synthesized under the technique stated in works [Dzhurik et al., 2008; Dzhurik et al., 2000].

The synthesized signal (Fig. 2) is scaled to the "etalon" presented by the most probable seismic model for the whole considered zone with intensity 9. Key parameters of model and signal are following: the thickness of the top layer is 10 m, velocities of seismic waves 2700 – Vp and 1450 – Vs, the maximum acceleration is 208 cm/s^2, the maximum of spectra is 39 cm/c, width of spectra with the level 0,5 of the maximum is from 1 to 8 Hz, duration of oscillations with the level 0,3 of the maximum is 20 seconds. The specified parameters of the initial signal show that it corresponds to intensity 8, and width of spectra characterizes its compliance with rather far (spectra maxima generally in the range of 0-3 Hz), and rather close (3-8 Hz) earthquakes from the allocated probable focus zones. When carrying out necessary calculations for linear constructions located in the zone with intensity 8 the synthesized signal (Fig. 2) was scaled to effect with intensity 7 for "etalon" rocky soils.

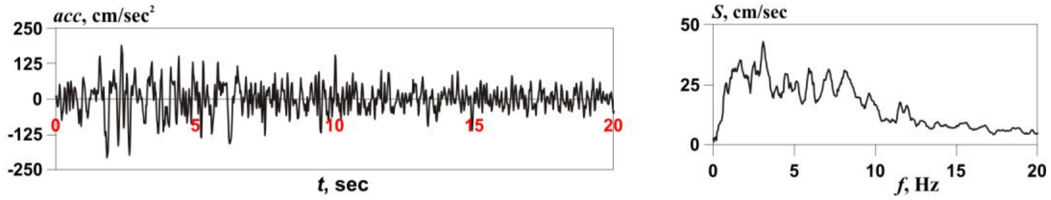

Figure 2. Initial signal and its spectra

Seismic microzonation of the route is carried out with using the method of seismic rigidity and microtremor. Measurements are obtained by this complex according to normative documents for seismic microzonation [Methodical recommendations…, 2004; Site effect assessment, 1988; Recommendations…, 1985] more than in 500 points. They were concentrated on difficult sites and constructing bridges and disseminated in rather uniform sites, presented by frozen soil with near surface rocky soils. As a result the assessment of seismic hazard of the route (seismic intensity and seismic accelerations) with using calculation methods is carried out. The frequency features of oscillations in the top profile zone were also estimated.

Calculation of accelerograms is carried out with using the amplitude-frequency characteristics of the top zone of the profile, obtained by means of microtremor method. They were determined by the relation of spectrum of horizontal component to vertical component, according to expression:

$$U(x) = \frac{H_N + H_E}{2V_Z} \tag{1}$$

where H_N, H_E – microtremor spectrum of horizontal components NS и EW, V_Z – spectra of vertical component «Z».

The scheme of measurements was developed to include all types of soil complexes presented in the railway line basis.

According to our approach route seismic zoning with using of chosen instrumental methods was executed in the beginning. And the whole route (with initial intensity 9), was divided into sites with seismic intensity 8, 9 and 10. According to soil conditions sites with intensity 8 are characterized generally by rocky and hard-frozen soils (T< - 2°C), sites with intensity 9 are characterized by plastic-frozen soils (T> - 2°C) and sites with intensity 10 are characterized by transitional zones from frozen to melted soil, water-saturated friable deposits (taliks of riverbeds).

In each zone average frequency characteristics were gained by microtremor method using a large number of points of measurements. For their further use they were transformed to frequency characteristics gained by records of earthquakes (Fig. 3) by multiplication of them by the value of the relation of coefficients in formulas for calculation of increments of intensity for microtremor method and amplitude-frequency method [Site effect assessment, 1988]. On all frequency curves (Fig. 3.1) vertical segments showed confidence interval for probability of P=0.9.

It should be noted that such transformation isn't absolutely correct because of using various sources of oscillations and applied methods of calculation of frequency characteristics. But considering that it is own characteristic of the top layer, and it is defined more by its parameters, instead of the source of oscillations, it is possible to consider that such approach is correct as a first approximation.

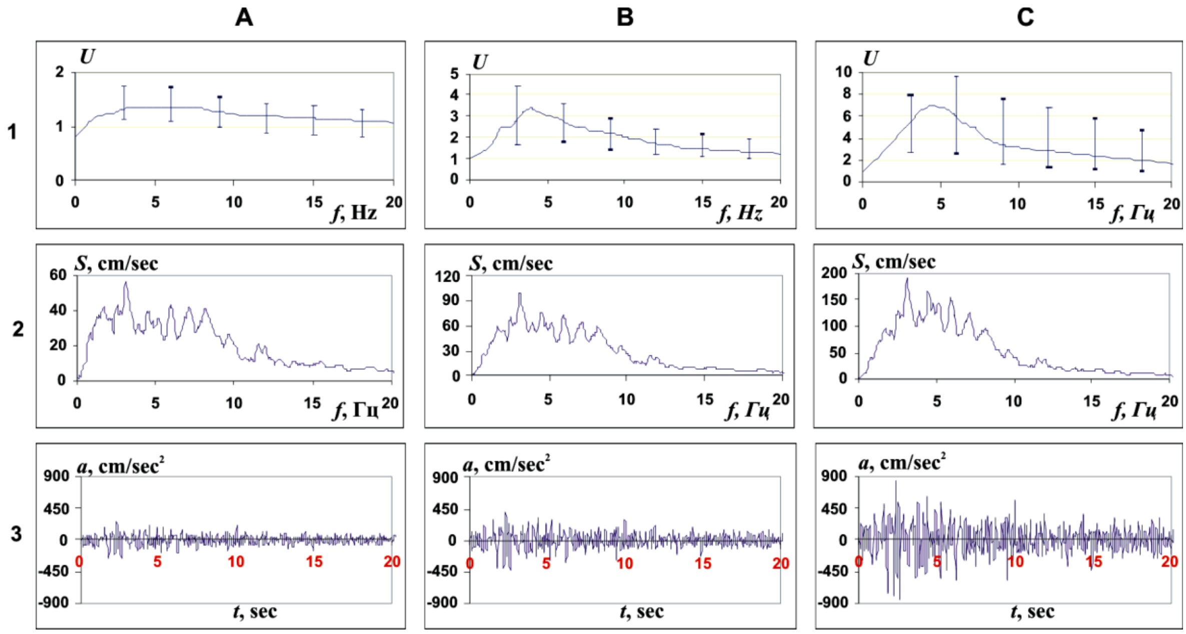

Figure 3. Average statistical frequency characteristics (1) for zones with intensity 8 (A), 9 (B) and 10 (C); average amplitude spectrum of signals for these zones (3) and accelerograms of large earthquakes for maximal horizontal component (2)

As a result it is received that the maximum values of levels of average frequency characteristics during transition from site to site (with seismic intensity from 8 to 9 and 10) vary within an error of changes in the relation close to 2 (1,4; 3,2; 6,8). The maximum value of the amplitude-frequency characteristic is related with resonant features of friable thickness, and this parameter was used for the assessment of seismic intensity of soil in relation to rocky soil [Methodical recommendations…, 2004; Site effect assessment, 1988]. Frequencies of the main maxima at the level of 0,7 are in wide limits from 1-2 to 9 Hz, and it has the explanations as the analysis joined the amplitude-frequency characteristics received in seismic zones with identical intensity, but for sites with various thickness of the top layer lying on rocky soils, taken for "etalon".

The obtained average frequency characteristics were used for synthesis of accelerograms of large earthquakes on layer surface also for each seismic zone. For this purpose the amplitude spectrum of the initial signal (Fig. 2) was multiplied by amplitude-frequency characteristics (Fig. 3.1) that led to obtaining spectra for studied zones (Fig. 3.2). Further by realization of inverse Fourier transform average accelerograms are calculated. They correspond to large earthquakes for specifically allocated zones with intensity 8, 9 and 10 (Fig. 3.3). The phase characteristic of the synthesized initial signal (Fig. 2) was used.

Calculated maximum accelerations for zones with intensity 8, 9 and 10 are equal to 268, 430 and 856 cm/s^2 – respectively. Taking into account confidence intervals of average frequency characteristic the dispersion of values is presented in a tabular form. For rocky ("etalon") and the hard-frozen soils (intensity 8) relative deviation from average is 0,3, for intensity 9 – 0,36 and for intensity 10 (water-saturated soils) do not exceed 0,4. As a result deviation does not exceed 0,5. It confirms possibility of use of experimental frequency characteristics for synthesis of accelerograms of large earthquakes on the surface in the presence of the synthesized initial signal, which parameters correspond to initial seismicity of the territory.

Using noted possibilities of the chosen complex of methods, we give examples of engineering and seismological assessment of two bridge constructions located on sites with initial seismicity of 9 and 10(Fig. 1): through river Kurung-Yuryakh (Fig. 4A) and through river Dagal-Dykan (Fig. 4B). Bridge constructions are the most responsible for the linear structure, because in most cases they are transitional zones from rocky and frozen to melted and water-saturated soils and from hard-frozen to plastic-frozen soils (Fig. 4).

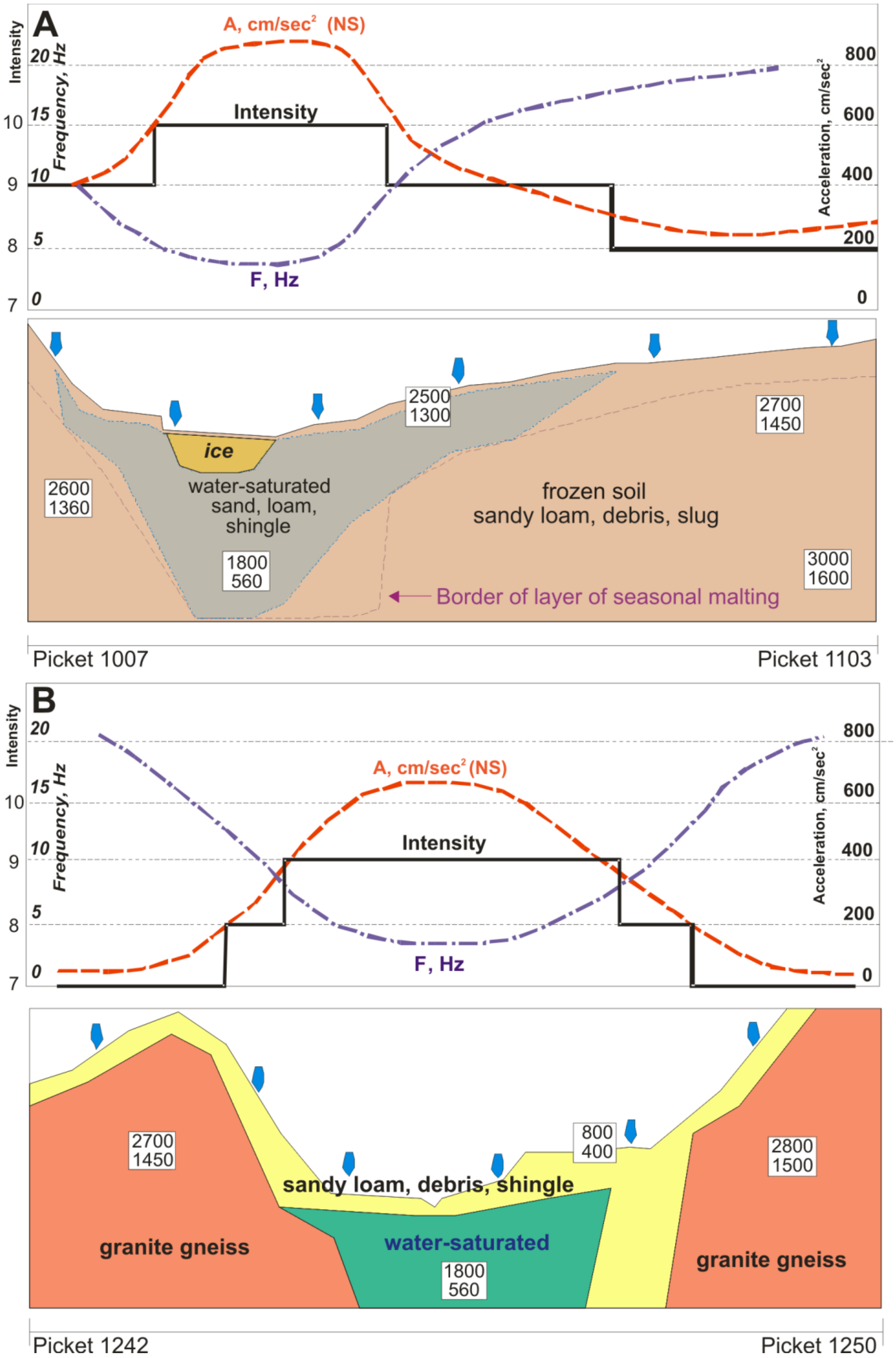

Figure 4. Engineering and seismological conditions of bridge constructions through rivers Kung-Yuryakh (A) and the Dagal-Dykan (B), located in zones with initial seismicity of 9 and 8 respectively. Velocities of seismic waves are presented in squares: at the top - Vp, at the bottom - Vs; shooters specified points of measurement seismic waves velocities and registration of microseisms

Table 1. Deviation calculated maximum accelerations from average

Seismic intensity of zones	A_{max} for minimum values of amplitude-frequency characteristic (cm/s^2)	**A_{max} for average values of amplitude-frequency characteristic (cm/s^2)**	A_{max} for maximum values of amplitude-frequency characteristic (cm/s^2)
8	201	**268**	351
9	236	**430**	578
10	527	**856**	1176

For considered bridge constructions for calculations of accelerograms we did not use average amplitide-frequency characteristics of microseisms (Fig. 3.1), but we used directly registered in points of the measurements noted by shooters in figure 4. Researches on site of the constructing route were conducted during the spring period (the beginning of intensive melting). It is possible to note that it is the optimum period of registration of useful signals both for seismic exploration and for a method of microseisms.

It is confirmed (Fig. 4) that visible velocity uniformity of soils completely does not define relative uniformity of seismic hazard, which has to change according to distribution of acoustic rigidity. In this case strength characteristics of soil which are defined by their structure, temperature and physical state are very important. Taking into account of these parameters for the whole studied route is carried out with use of temperature of permafrost, water-saturating of soils using the method of seismic rigidity, frequency characteristics according to the microtremor method and calculation methods.

According to the conducted calculations the intensity of chosen sites are divided into 8, 9 and 10 (the 1st bridge construction) and 7, 8 and 9 (the 2nd bridge construction). For maximum horizontal component peak accelerations vary from 241 to 888 cm/s2 in the first case, and from 117 to 432 cm/s2 in the second case. Resonant frequencies have the minimum values for riverbeds 4,7 and 3,2 Hz and increase during transfer to coastal sites to 20 Hz. With similar approach to seismic zoning the whole railway line (Fig. 1) is also divided into intensity 8, 9 and 10 (the 1st site with the initial seismicity equal to 9) and 7, 8 and 9 (the 2nd site with initial seismicity of 8).

CONCLUSIONS

The analysis carried out above can be considered as generalization of the obtained results of seismic zoning of the railway route in the direction of more rational use of experimental frequency characteristics for calculations of accelerograms of large earthquakes, which parameters correspond to initial seismicity of the area. Data of the complex of calculation and instrumental methods of seismic zoning (seismic rigidity and microtremor) were a basis for gaining accelerograms, spectra of accelerations and frequency characteristics. As a result the set of necessary data for the assessment of engineering and seismological conditions of the linear structure by the technique offered above is gained. Thus if we have sufficient statistical justification of characteristics registered by instrumental methods of seismic zoning and reasonable synthesizing of the initial signal (taking into account key parameters of source zones) is provided the necessary set of parameters of seismic effects for construction of aseismic linear structures. (The reported study was partially supported by RFBR, research projects No. 14-05-31359 and No. 14-05-00200)

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