DESIGN OF SPECIFIC SITE RESPONSE SPECTRUM

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ABSTRACT :

Parameters of response spectra must be reciprocal from physical point of view. Therefore these parameters can't be set independently. To study the basic properties of spectra one must be normalized to level and predominant frequency. The averaged spectrum shape is more simply when double logarithmic scale is used. It is possible to approximate the spectrum slopes by straight lines. The normalized spectrum has one parameter only: *S*, logarithmic width of the spectrum. This parameter is defined as the difference between the logarithms of the frequencies of spectral half-maximum points (on the high- and low frequency slopes of the spectrum). Correlations between different parameters of response spectra with 5% damping were provided using 802 records of most intensive horizontal components. The processing of strong ground motion records shows that the correlation between parameters is considerable. The value of *S* is very stable disregard to earthquake magnitude, source mechanism, distance and ground condition. Influence of these factors is estimated. It is shown, that response spectrum for acceleration is practically symmetrical in double logarithmical scale. The mean spectrum slopes are proportional to frequency. The spectrum slopes are estimated also for different confidence levels. It is possible to estimate the media quality Q from parameters of response spectrum. The quality Q and logarithmic spectrum bandwidth are functionally connected. Thus to design the site specific one need to estimate expected level of ground acceleration and expected predominant period. The empirical relations to estimate these values are proposed.

KEYWORDS: response spectrum, frequency bandwidth, predominant period, duration, coefficient of dynamic amplification

1. THE SPECTRUM PARAMETRIZATION

The response spectrum parameters for a single record can be described by a set of parameters. These parameters must be reciprocal from physical point of view. Therefore design spectrum parameters can't be set independently. To study the basic properties of spectra one must be normalized to level and predominant period. The world-average dependence of the predominant period of the ground vibrations on various factors has the form [Aptikaev, Erteleva, 2002] $\lg T = 0.15\, M_S + 0.25 \lg R + C_1 + C_2 \pm 0.2$, where R – is hypocentral distance in km, if $\lg R < \lg R_1 = 0.33\, M_S - 0.61$, value R_1 is used in calculations; the constant C_1 is equal to - 0.1 for reverse (thrust), 0.0 – for strike-slip and 0.1 for normal faulting. The coefficient C_2 depends on local tectonic conditions; average value is equal to $C_2 = -1.9$. For a single region the standard deviation reduced down to ± 0.1 [Mahdavian et al., 2005]. So the normalized to level and predominant period spectrum describes the shape of spectrum. The averaged spectrum shape is more simply when double logarithmic scale is used. As a rule acceleration spectrum has only one maximum. It is possible to approximate the spectrum slopes by straight lines (Figure 1). One can describe the normalized spectrum by following parameters: maximum level (the dynamic amplification coefficient β), skewness of the spectrum estimated by the comparison of the frequency ranges on both sides of the predominant period T_0:

$$S_1 = \lg f_{\mathrm{high}} - \lg f_0 \text{ and } S_2 = \lg f_0 - \lg f_{\mathrm{low}}.$$

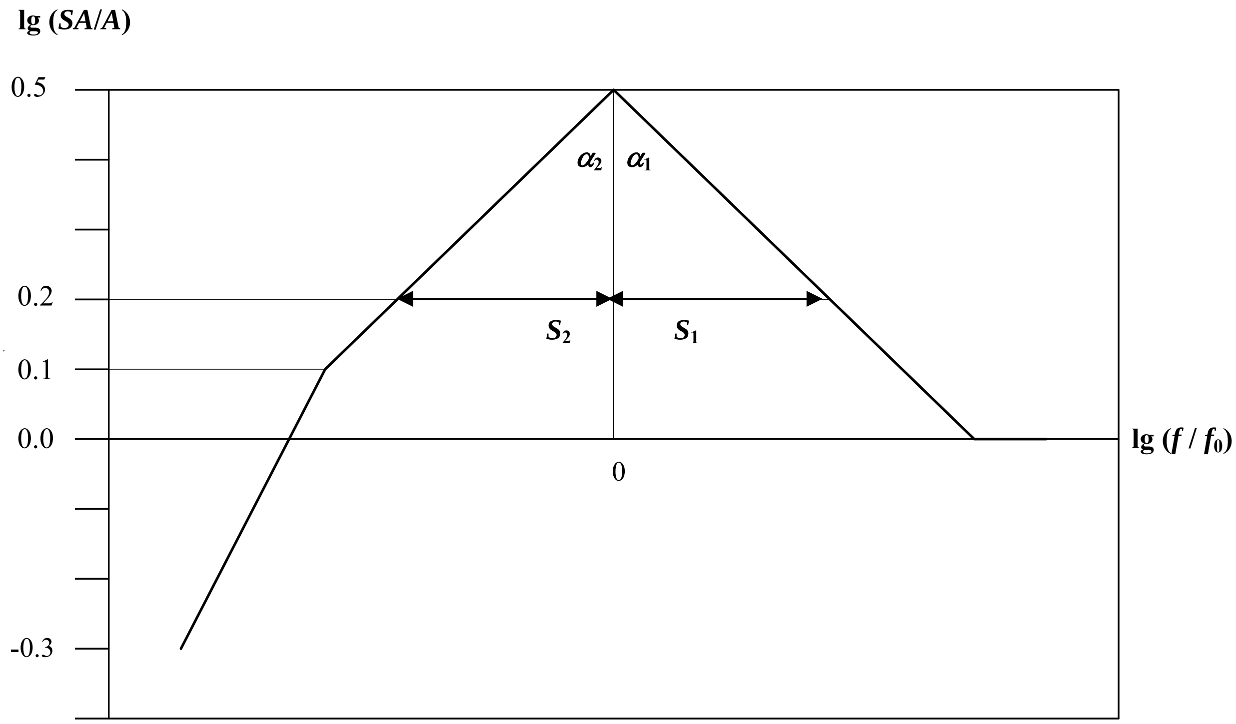

Figure 1 The scheme of spectrum parameterization

The total logarithmic width S of spectrum $S = S_1 + S_2$ is defined as the difference between the logarithms of the periods (or frequencies) of spectral half-maximum points (on the high- and low frequency slopes of the spectrum). The slope steepness is determined by values S_1 and S_2.

2. LOGARITHMIC SPECTRUM BANDWIDTH

The value of S is very stable: $S = 0.60 \pm 0.24$ disregard to earthquake magnitude, faulting type, distance and ground condition at the point of observation (Figure 2). The correlation coefficient with magnitude is about 0.13. The correlation coefficient with logarithm of distance closest to rupture surface is the same. Stability of S is used to design response spectra of strong earthquake using records of weak local earthquakes [Aptikaev, Erteleva, 2005].

We have investigating dependence of the logarithmic width of spectra on various factors:

$$S = 0.6 + C_1 + C_2 \pm 0.22,$$

where coefficient C_1 is equal to - 0.10 for the reverse (thrust) faulting, 0.00 for the strike-slip, and 0.10 for the normal faulting; coefficient C_2 is equal to - 0.05 for a rock and 0.2 for a soft soil. For the intermediate ground $C_2 = 0.00$. The difference of high- and low- frequency parts of spectra is shown on the Figure 3.

As a rule, the value of S_1 is somewhat larger. Such a difference is slighting for practical use. Therefore it is possible to consider the response spectra symmetrical and determine f_0 as $f_0 = (f_{high} * f_{low})^{0.5}$. Such determination reduces the standard deviation for the f_0. So, it is enough only one parameter S to describe the frequency content of response spectra. We have examined the dependence of S-value on shaking duration. The duration d (pulse width) we determine as time interval between the first and the last cases amplitude is equal to half of maximum one.

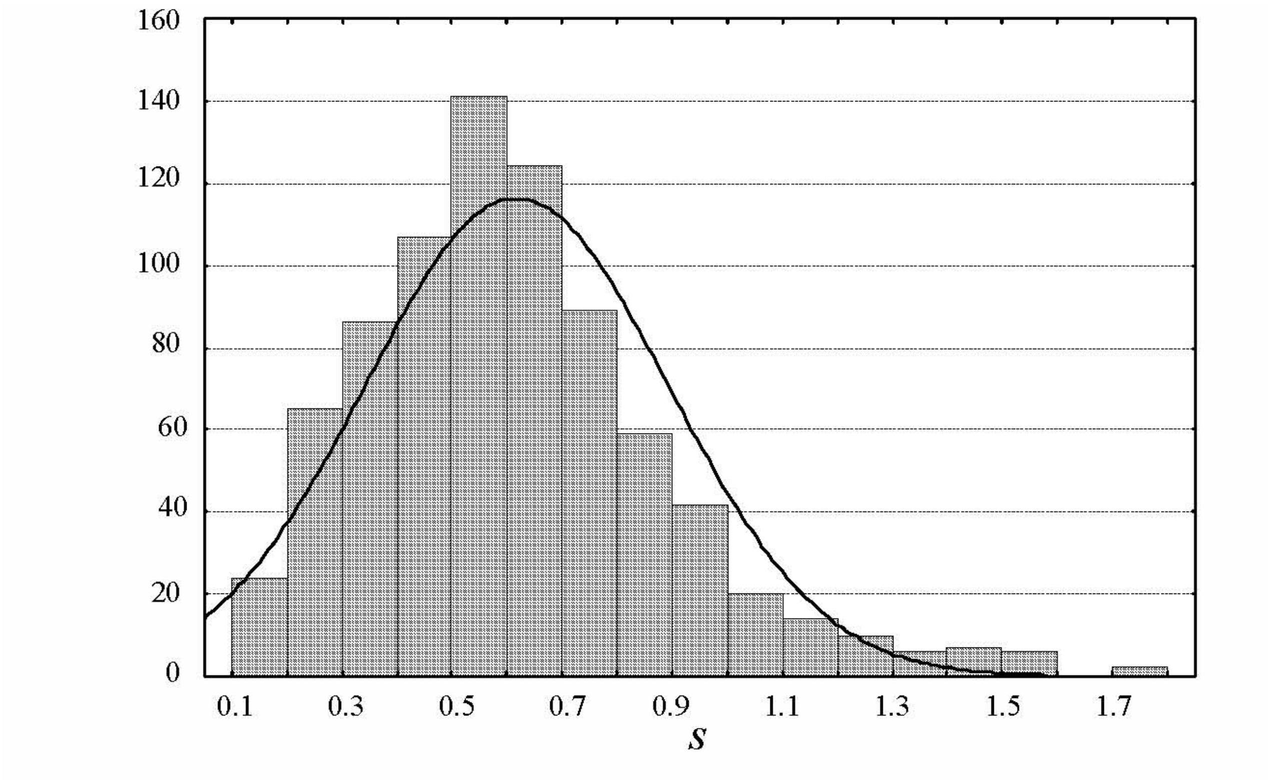

Figure 2 Distribution of logarithmic frequency bandwidth *S*.
The envelope is Gaussian distribution with parameters 0.60 ± 0.24 (mean and standard deviation)

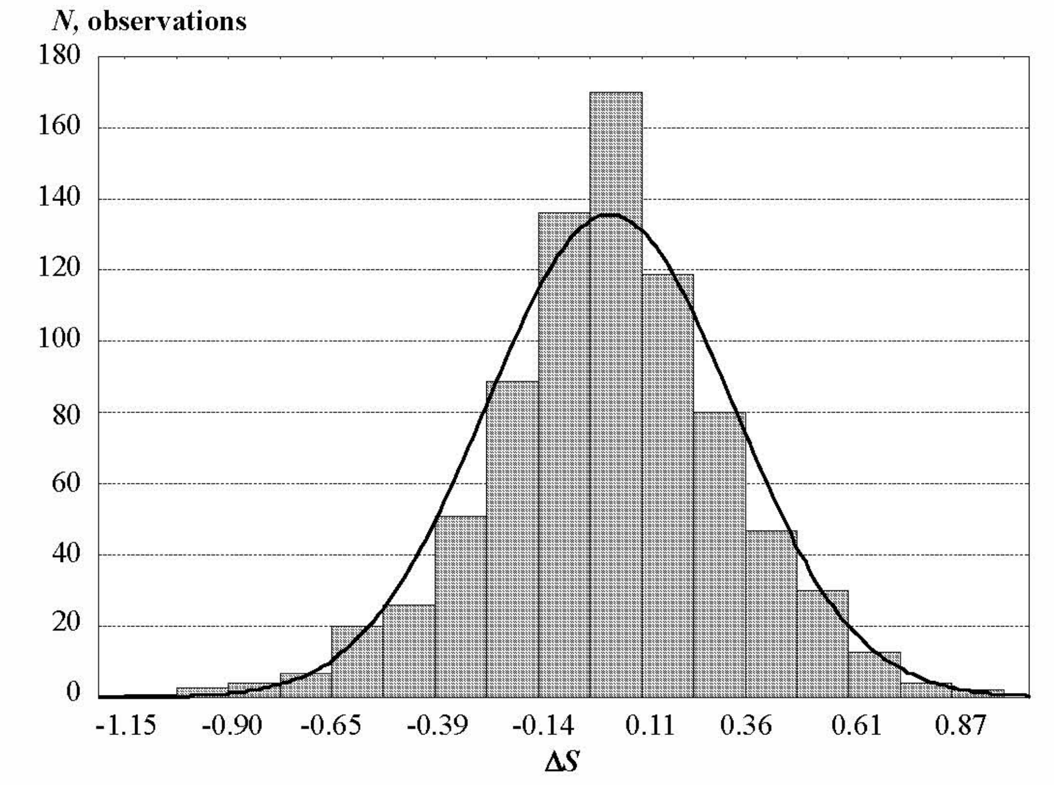

Figure 3 Distribution of S_1 - S_2.
The envelope is Gaussian distribution with parameters 0.02 ± 0.27 (mean and standard deviation)

The duration can be calculated using empirical equation [Aptikaev, Erteleva, 2002]:

$$\lg d\text{, sec} = 0.15\, M_S + 0.5 \lg R\text{, km} + C_1 + C_2 - 1.3,$$

where C_1 is equal to 0.25 for normal faulting, 0.00 for strike-slip and – 0.25 for reverse (thrust) faulting; C_2 is equal to – 0.15 for rock, C_2 = 0.20 for soft soil and C_2 = 0.00 for intermediate ground conditions.

If $\lg R < \lg R_1 = 0.33\, M_S - 0.61$, value R_1 is used in calculations. The empirical relation is (Figure 4):

$$S = 0.60 + 0.1 \lg d \pm 0.27.$$

Correlation coefficient is equal to 0.23 (significant).

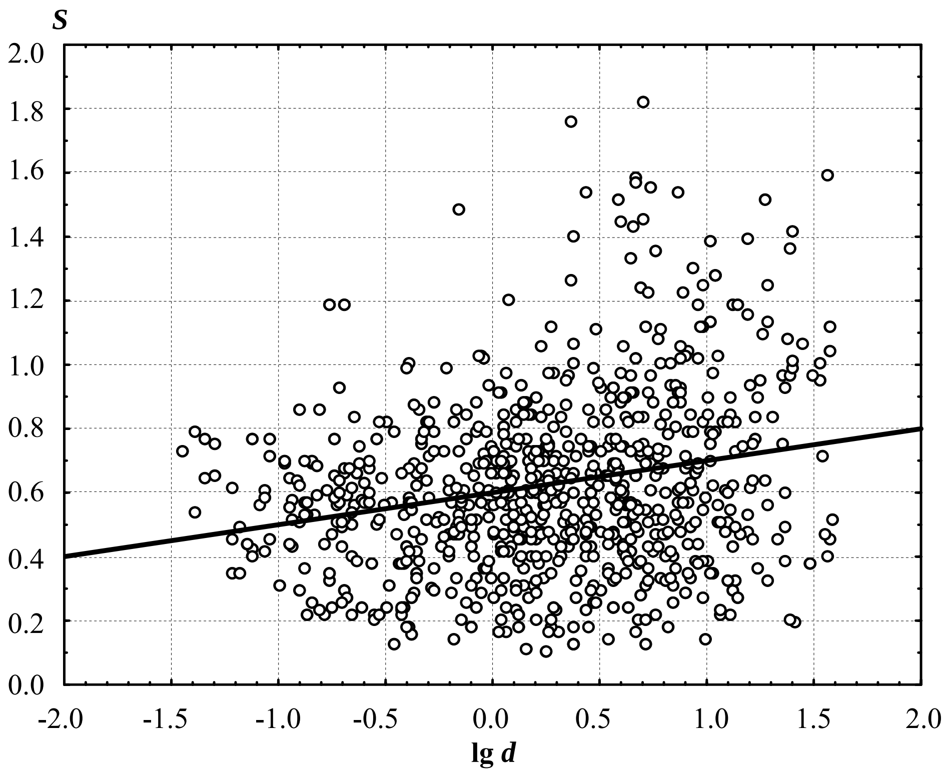

Figure 4 Dependence of the logarithmical bandwidth S on the logarithm of duration lg d

3. SLOPES OF SPECTRUM

The mean spectrum slopes are defined by S-value and are proportional to $f^{\pm 1}$. This relation was met in the NPP Codes of Japan and Canada. For the 67% confidence level of non-exceeded the steepness of the spectrum slopes is reduced: $\alpha = arc\ tg\ 6/7$; α is the angle between line of spectrum slope and vertical (see Fig. 1).

For the 84% confidence level $\alpha = arc\ tg\ ¾$. Using the experimental data the mean relation of predominant periods of velocity and acceleration is about 2.5 and the long period spectrum slope is proportional to f^{-2} after point related to $\lg \beta = 0.1$ dec. log. unit.

4. QUALITY OF OSCILLATION SYSTEM

The quality (Q) of oscillation system including both source and ground properties is described by expression

$$Q = f_0 / (f_{high} - f_{low}).$$

This definition of quality is used in mechanics and electronics, and differ from usually used in seismology. The distribution of lg Q is shown on the Figure 5.

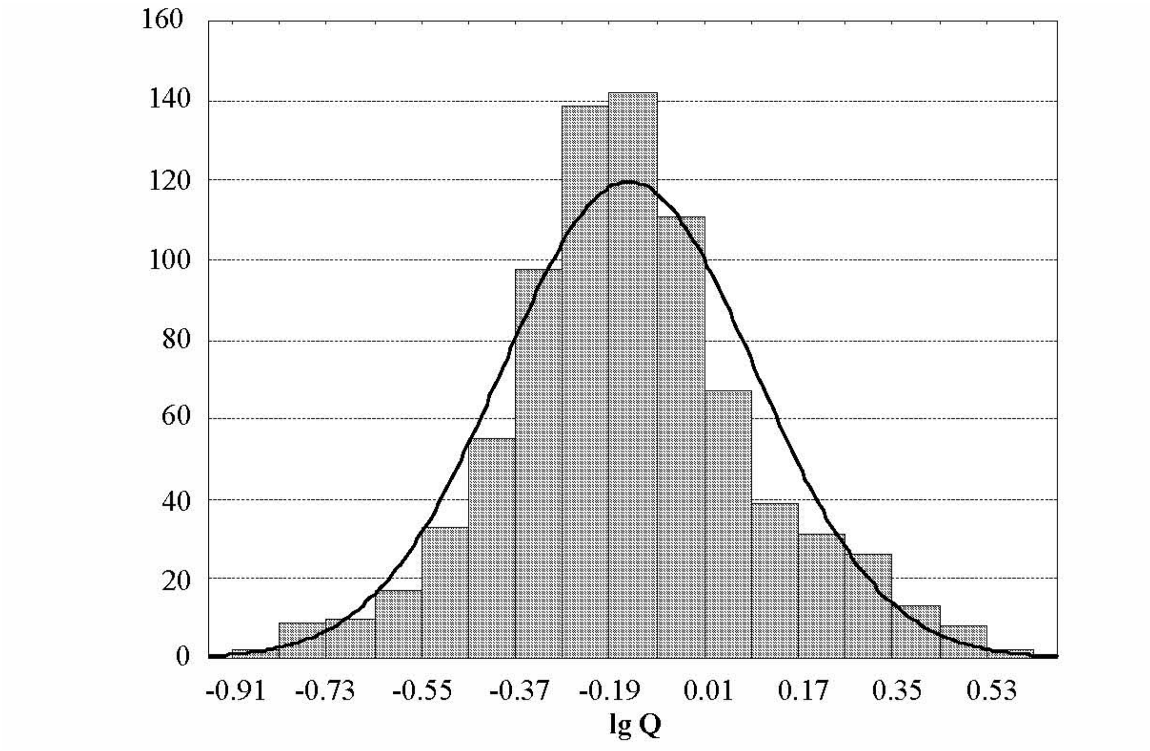

Figure 5 Distribution of lg Q.
The envelope is Gaussian distribution with parameters - 0.16 ± 0.24 (mean and standard deviation)

It should be noted, that we are using the decimal logarithms and frequency bandwidth at spectra level of 0.5 from maximum. The quality Q and logarithmic spectrum bandwidth *S* are functionally connected. The linear approximation of this relation has the form: lg Q = 0.41 - *S* ± 0.08. So, quality of any oscillation system can be estimated by value of *S*.

5. DYNAMIC AMPLIFICATION COEFFICIENT

Distribution of the dynamic amplification coefficient disregard to earthquake magnitude, faulting type, distance and ground condition is shown on the Figure 6. For the rock and soft soil we obtain practically the same value because of influences of *S* and duration compensates each other.

$$\lg \beta = 0.56 \pm 0.10,$$

The value of the coefficient beta is relative stable. According to Russian Code for NPP residuals of synthetic accelerogram spectrum from target one must be less than 10%. It is clear, that this threshold can be enlarged at least to 15%.

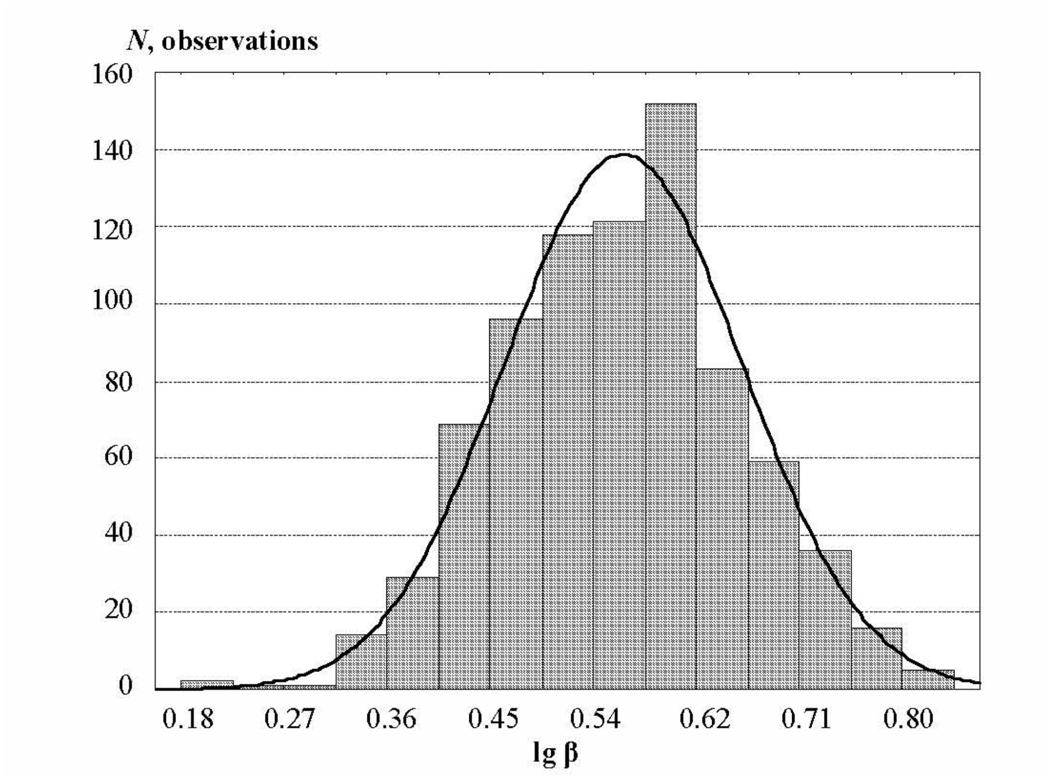

Figure 6 Distribution of lg β.
The envelope is Gaussian distribution with parameters 0.56 ± 0.10 (mean and standard deviation)

From physical point of view the coefficient of dynamic amplification must be tight connected with oscillation system quality. Using the orthogonal regression one can obtain the linear equation (Fig. 7):

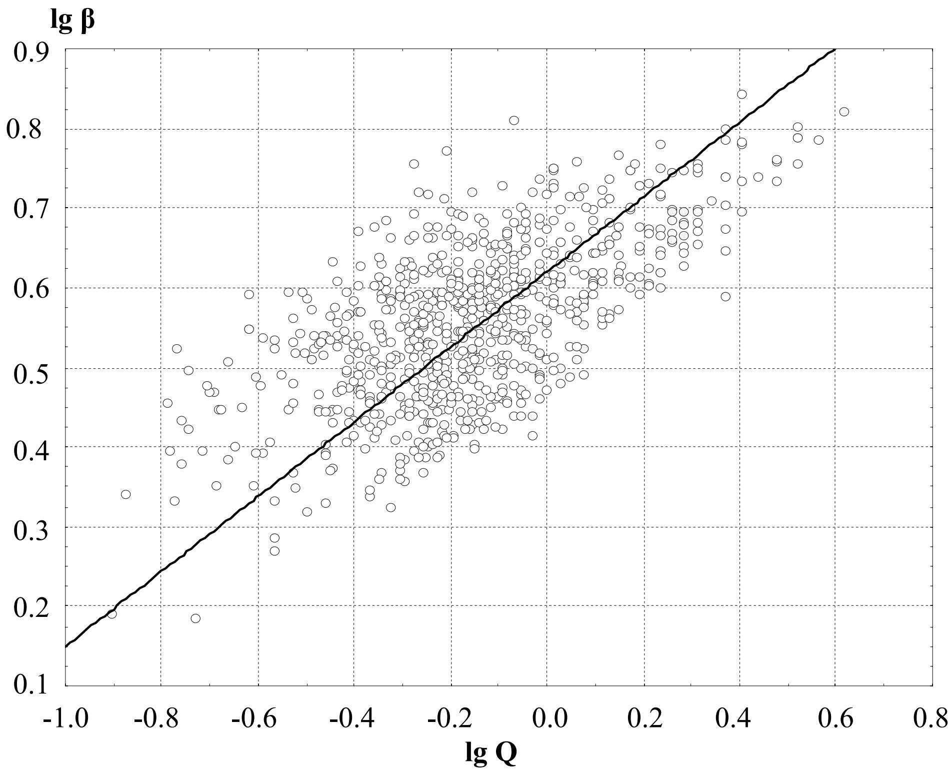

Figure 7 Relation between lg β and lg Q (orthogonal regression)

$$\lg \beta = 0.62 + 0.47 \lg Q \pm 0.08,$$

correlation coefficient is k = 0.65.

It is more convenient to use the bandwidth S instead of quality Q, because of last value can be estimated directly from accelerograms (Fig. 8).

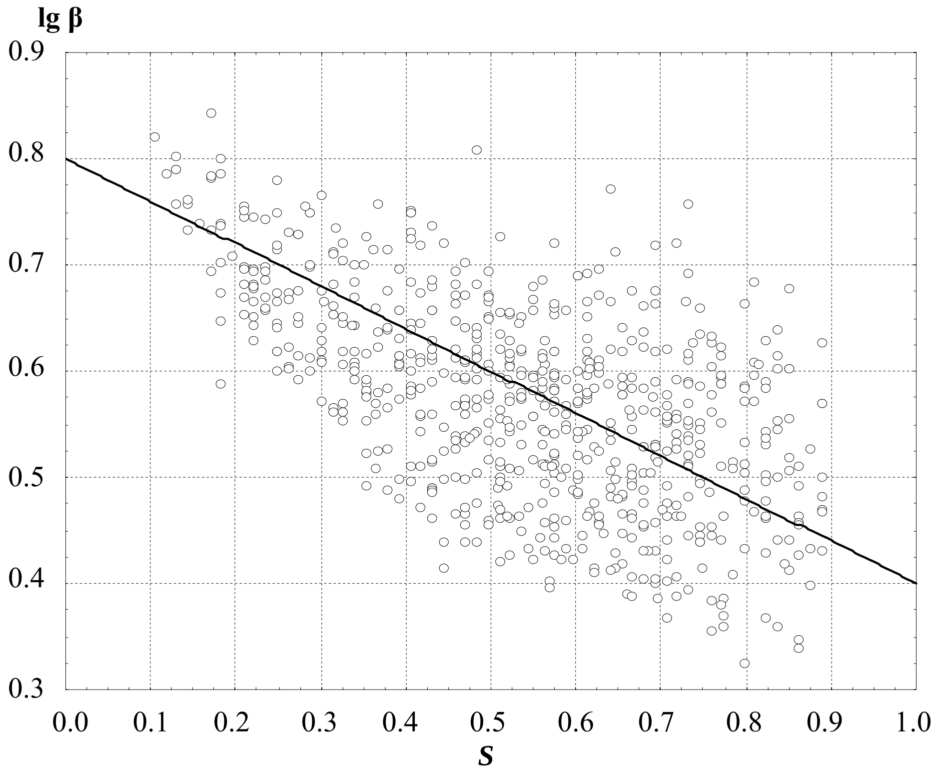

Figure 8 The relation of logarithm of coefficient β and bandwidth S

The obtained linear equation has the form:

$$\lg \beta = 0.80 - 0.40\, S \pm 0.08.$$

The correlation coefficient is equal to k = - 0.61.

It is usually believed that dynamic amplification depends on a shaking duration. We determine the duration or pulse width as the time interval between the first and the last cases of amplitude envelope is equal the half of maximal amplitude. We obtain using the orthogonal regression:

$$\lg \beta = 0.54 + 0.13 \lg d \pm 0.10$$

by significant correlation coefficient k = 0.38 (Fig. 9).

When both duration and bandwidth are taken into account one can obtain

$$\lg \beta = 0.72 - 0.28\, S + 0.07 \lg d \pm 0.07.$$

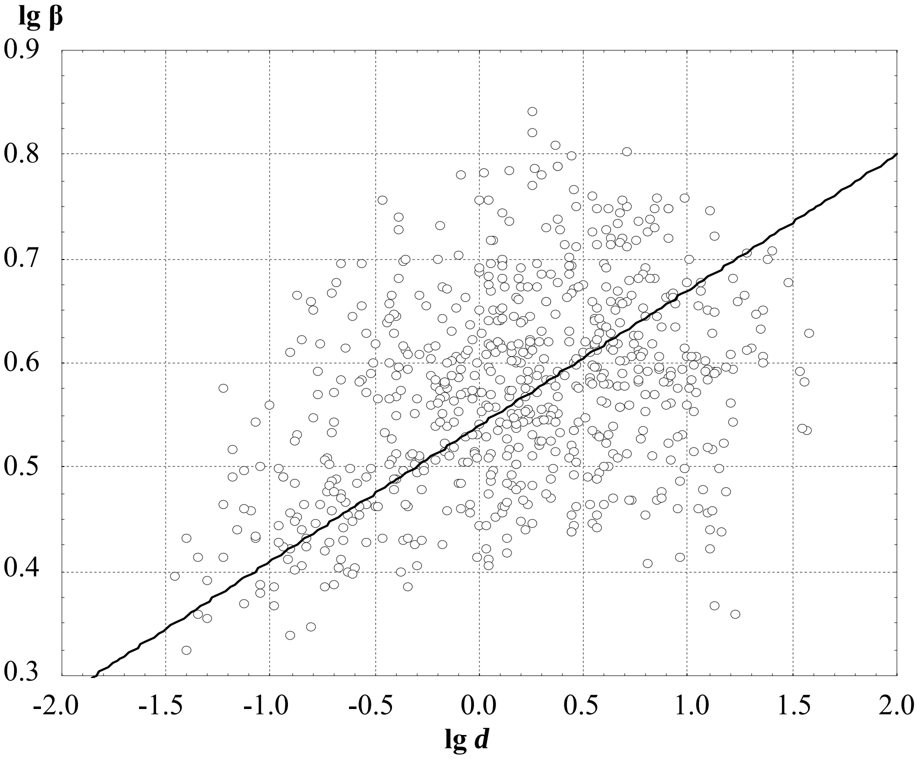

Figure 9 The relation of lg β and lg*d*

6. CONCLUSIONS

Main obtained results are:

1) There are some interconnections between different parameters of response spectrum and source and ground conditions.

2) Stability of frequency bandwidth *S* gives the possibility to process all the local records together disregard to earthquake magnitude and other source and recording site characteristics to predict relative frequency bandwidth for expected strong earthquake.

3) The coefficient of dynamic amplification β depends on bandwidth *S* and shaking duration *d.* The larger is bandwidth *S* – the lower is coefficient of dynamic amplification β. The larger is shaking duration– the larger is coefficient of dynamic amplification β.

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