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Assessment of the influence of epicentral distance of mining shocks on the transition of free-field vibrations to building foundations

Ocena wpływu odległości epicentralnej wstrząsu górniczego na przekazywanie drgań z podłoża na budynek

Abstract

The paper deals with the analysis of measurements of vibrations induced by mining rockbursts in the Legnica–Glogow Copperfield District (LGCD) to estimate the influence of mining tremor epicentral distance on the curve of relationship (*RRS*) between the response spectra from the simultaneously measured ground and building foundations vibrations. Non-dimension acceleration response spectra (β) as well as dimension acceleration response spectra (S_a) from the horizontal vibrations were taken into account. The focus is on apartment buildings – medium-rise and high-rise buildings. Additionally, a comparison of conclusions of research carried out in the case of response spectra with the corresponding earlier results regarding the reduction of maximum values of accelerations of vibrations during the transfer from the ground to building foundations were performed.

Keywords: mining tremors, epicentral distance, response spectra, ground vibrations, foundation vibrations, transmission of vibrations, apartment building

Streszczenie

W pracy dokonano analizy wyników pomiarów drgań górniczych w Legnicko-Głogowskim Okręgu Miedziowym (LGOM) w celu oceny wpływu odległości epicentralnej wstrząsu górniczego na postać krzywej relacji (*RRS*) spektrum odpowiedzi od drgań gruntu i spektrum odpowiedzi od jednocześnie mierzonych drgań fundamentu budynku. Pod uwagę wzięto bezwymiarowe przyśpieszeniowe spektra odpowiedzi (β) i odpowiednie spektra wymiarowe (S_a) policzone na podstawie drgań poziomych. Skupiono się na budynkach mieszkalnych – budynku średniej wysokości i budynku wysokim. Dodatkowo dokonano porównania wniosków z badań przeprowadzonych w przypadku spektrów odpowiedzi, z wcześniejszymi wynikami uzyskanymi w odniesieniu do redukcji maksymalnych wartości przyśpieszeń drgań przy ich przekazywaniu z gruntu na fundamenty budynków.

Słowa kluczowe: wstrząsy górnicze, odległość epicentralna, spektra odpowiedzi, drgania gruntu, drgania fundamentu, przekazywanie drgań, budynek mieszkalny

1. Introduction

Underground mining exploitation can result in randomly occurring mining shocks. This type of free-field vibration is a kinematic forcing for surface structures, and the vibrations are classified as so-called paraseismic vibrations. Mining-related vibrations stand out among the greatest intensity of paraseismic vibrations. It is therefore essential to assess the impact of this type of vibration on buildings.

During the transition of vibrations from the free-field to the building there is the phenomenon so-called dynamic soil-structure interaction. Simultaneously occurring free-field and building foundation vibrations may vary substantially [4, 8, 11, 12, 15]. It should be appreciated that the foundation vibrations allow for more accurate assessment of the harmfulness of vibrations to buildings than free-field vibrations [10]. Therefore it is particularly significant and important in practice to assess the vibrations transition to the foundations of the structure.

A simple and often used method for assessing the transition of free-field vibrations to the building foundation is to compare the maximum values of the vibrations of the building foundation and the ground next to the building recorded at the same time [2, 9, 14]. Analysis of the results of measurements of vibrations caused by mining tremors in respect to the reduction of the maximum value of the horizontal components of acceleration and velocity at their transition from free-field to the foundation of the building leads to the conclusion that the size of this reduction is a function of many variables: the mining shock energy, epicentral distance, the direction of wave propagation, maximum value of ground vibrations, vibration direction (parallel to the longitudinal or transverse axis of the building), and the dominant frequency of vibrations of the ground next to the building [5–7, 9].

In this study we focused on assessing the impact of epicentral distance of mining shocks on a curve of relationship (ratio) of response spectrum from the vibrations of the building foundation and the response spectrum from simultaneously measured free-field vibrations (*RRS – Ratio of Response Spectra*). Dimensionless acceleration response spectra from horizontal vibrations (β) and dimensional spectra (S_a) were taken into account, calculating on the basis of them the respective relationships *RRS*(β) and *RRS*(S_a). The influence of the type of building on relationships *RRS*(β) and *RRS*(S_a) was also analysed in the subsequent ranges of epicentral distances.

Additionally, a comparison of the conclusions from studies using response spectra with previous results [9] obtained in relation to the reduction of the maximum values for vibration acceleration at the transition from free-field to the building foundations was performed.

It is worth mentioning that the use of response spectra and their relationships *RRS* for studying the differences in the simultaneously recorded free-field vibrations and building foundation is a more advanced approach in the analysis of the dynamic soil-structure interaction than the use the maximum values of vibrations for this purpose [3, 4, 8, 12, 13].

2. Experimental studies – scope of the analysis

The source of vibration was mining shocks originating from underground exploitation in the Legnica–Głogow Copper District (LGCD). Only records induced by rockbursts with energy higher than 10^6 J and horizontal components of peak ground accelerations larger than 10 cm/s² were analysed. The epicentral distances of the mining shocks considered are in the range $re = 270 - 5839$ m.

The differences between simultaneously occurring free-field vibrations next to the building and its foundation for residential buildings: the medium-rise building S (5-storey) and high-rise building *W* (12-storey), were analysed. These are prefabricated structures. Building S is constructed using the large-block system and building *W* is erected as a large panel structure. Both buildings have basements, foundations in the form of continuous footings and they are located close together under one housing estate.

The natural fundamental frequency f_1 experimentally determined in horizontal directions of the building S is equal 2.9–3.3 Hz in a direction parallel to the transverse axis (x) and 2.9–3.1 Hz in a direction parallel to the longitudinal axis (y). On the other hand, in building W the natural fundamental frequency f_1 experimentally determined in horizontal directions is equal 1.44–1.50 Hz in a direction parallel to the axis (x), and 2.06–2.17 Hz in a direction parallel to the longitudinal axis (y) [12].

Acceleration records of free-field vibrations next to the building and on the building foundation were measured simultaneously using the so-called "armed partition" accelerometers for each of the mining shocks considered. Accelerometers on the ground were placed a few metres away from a building.

The focus is on the horizontal components of vibration accelerations, respectively parallel to the transverse axis (x) and longitudinal (y) of each of the buildings.

Both dimensionless spectra β and dimensional spectra S_a were calculated on the basis of assumed free-field and building foundation acceleration vibrations. An averaged fraction of critical damping equalling about 3% was adopted in the calculations according to dynamic experimental investigations presented in [1].

The number of analysed pairs (free-field – building foundation) of acceleration response spectra (β and S_a) in the successive ranges of epicentral distances are listed in Table 1.

Table 1. Summary of the number of analysed pairs (free-field – building foundation) of response spectra (β and S_a) in the successive ranges of epicentral distances

***re* [m]**	**Building S**		**Building *W***	
	β	S_a	β	S_a
to 500	2	2	3	3
501–800	26	29	11	12
801–1100	22	28	44	51
1101–1700	25	27	17	23
1701–2500	34	44	24	41
over 2501	44	60	25	47
whole range	153	190	124	177

3. The influence of epicentral distances of mining tremors on the transition of free-field vibrations to the building foundations

Dimensionless acceleration response spectra (β) from horizontal vibrations and the corresponding dimensional spectra (S_a) calculated using simultaneously recorded free-filed vibrations next to the building and the building foundation were used to try to assess the impact of epicental distances of mining tremors on the transition of free-field vibrations to the building foundations.

The pairs of response spectra (free-field – building foundation) thus determined were used for calculation using the formula (1) the relationship (ratio) $RRS(\beta)$ for the dimensionless acceleration response spectra (β), and a calculation using the formula (2) the relationship (ratio) $RRS(S_a)$ in the case of dimensional acceleration response spectra (S_a).

$$RRS(\beta) = \frac{\beta_f}{\beta_g} \tag{1}$$

$$RRS(S_a) = \frac{S_{af}}{S_{ag}} \tag{2}$$

where:

- $RRS(\beta)$, $RRS(S_a)$ – relationship (ratio) describing the transition of response spectra from the free-field to the building foundation in the case of dimensionless and dimensional acceleration response spectra respectively,
- β_f, S_{af} – respectively dimensionless and dimensional acceleration response spectrum originating from the building foundation vibrations,
- β_g, S_{ag} – respectively dimensionless and dimensional acceleration response spectrum obtained on the basis of free-field vibrations next to the building.

Separately, for building *S* and *W*, each of the relationships $RRS(\beta)$ and $RRS(S_a)$ defined for each of the considered mining shocks are placed into one of six groups. The criterion for assigning *RRS* relation to the group was the epicentral distance of the mining shock. Successive ranges of epicentral distances which correspond to the established relationship groups *RRS* are given in Table 1.

Averaged relationships were determined in each set of relationships $RRS(\beta)$ and $RRS(S_a)$. They corresponded to the range of epicentral distances. Furthermore, averaged relationships $RRS(\beta)$ and $RRS(S_a)$ were also calculated in the whole range of epicentral distances of the mining shocks, both in the case of building S and building *W*.

Referring to the building S, Fig. 1 shows relationships $RRS(\beta)$ and $RRS(S_a)$ averaged in intervals of epicentral distances of the mining shocks. Analogous curves designated for the building *W* are given in Fig. 2.

Additionally, Table 2 shows the values $RRS(\beta)$ and $RRS(S_a)$ averaged within the adopted ranges of epicentral distances corresponding to mean values of the natural fundamental frequency f_1 in the *x* and *y* directions of building *S* and building *W*.

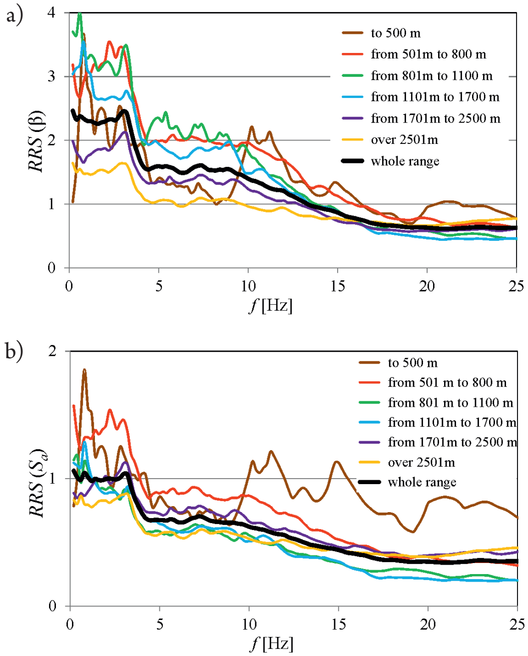

Fig. 1. Relations *RRS* averaged in the ranges of mining tremors epicentral distances – building *S*: a) *RRS*(β); b) *RRS*(S_a)

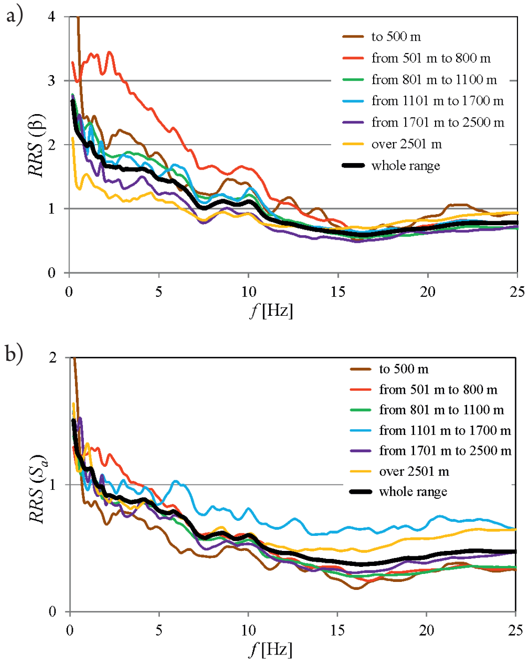

Fig. 2. Relations *RRS* averaged in the ranges of mining tremors epicentral distances – building *W*: a) *RRS*(β); b) *RRS*(S_a)

In Fig. 1 and Fig. 2 significant differences in the curves *RRS*(β) and *RRS*(S_a) which were obtained by averaging of the collections referring to individual ranges of epicentral distances, are visible. In addition, the graphs *RRS* made for the epicentral distance ranges are clearly distinguishable from charts averaged over the range of distances. These applications relate to the transition of vibrations from the free-field to the foundations of the building *S* and the building *W*.

Table 2. Values of RRS(β) and RRS(S_a) corresponding to the frequencies of natural vibrations f1 of *S* and *W* buildings, averaged in the successive ranges of epicentral distances

***re* [m]**	**Building S – f_1 = 3 Hz**		**Building W – f_1 = 1.8 Hz**	
	RRS(β)	*RRS*(S_a)	*RRS*(β)	*RRS*(S_a)
to 500	2.41	1.19	2.18	0.77
501–800	3.45	1.46	3.11	1.17
801–1100	3.41	0.91	1.89	0.90
1101–1700	2.68	0.87	2.05	1.08
1701–2500	2.11	1.12	1.72	1.07
over 2501	1.64	0.88	1.30	0.93
whole range	2.45	1.04	1.80	0.98

In the case of curves *RRS*(β) and *RRS*(S_a) relating to building *S* as well as in the case of *RRS*(β) referring to building *W*, these differences are especially evident at frequencies important from a practical point of view, namely in the relatively low frequency range (to approx. 10 Hz).

Both in the case of building *S* and building *W*, in ordinates of relationship *RRS* referring to the dimensionless acceleration response spectra (β), there are bigger differences in the individual ranges of epicentral distance than in the same relationship *RRS* based on dimensional acceleration response spectra (S_a).

Substantial differences may occur in the values (ordinates) *RRS*(β) and *RRS*(S_a) corresponding to the natural fundamental frequencies of the buildings, calculated in the individual ranges of epicentral distances. This is evident in Table 2. For example, both in the case of building *S* and building *W*, the value *RRS*(β) in the range of epicentral distances within 501–800 m is approximately twice as high as that calculated for epicentral distances within the range over 2.501 meters. However, the differences in the *RRS* values corresponding to the natural fundamental frequencies of the buildings from the individual intervals of epicentral distances, in relation to the values *RRS* averaged over the range of epicentral distances, reach tens of percent (building *S*: *RRS*(β) – approx. 30%, *RRS*(S_a) – approx. 40%; building *W*: *RRS*(β) – approx. 70%, *RRS*(S_a) – approx. 20%).

In addition, the relationships *RRS*(β) averaged in the dedicated ranges of epicentral distances of mining shocks (the whole range, from 501 m to 800 m, from 801 m to 1100 m, from 1101 m to 1700 m, from 1701 m to 2500 m and over 2501 m) in the case of the medium-rise building S and the high-rise building W, are compared in Fig. 3. The same comparison referring to the relationship *RRS*(S_a) is made in Fig. 4.

Practically, in most of the individual ranges of epicentral distances a significant dependence of differences in the relationship *RRS*(β) referring to the different building construction of buildings *S* and *W* against epicentral distance is not seen. However, in some ranges of the epicentral distances such a relationship can be seen, for example from 801 m to 1100 m and 1101 m to 1700 m.

In general, in the case of curves $RRS(S_a)$ this dependence is much less clear than for the *RRS*(β). The differences are relatively small. An exception here may be ranges from 501 m to 800 m and from 1101 m to 1700 m.

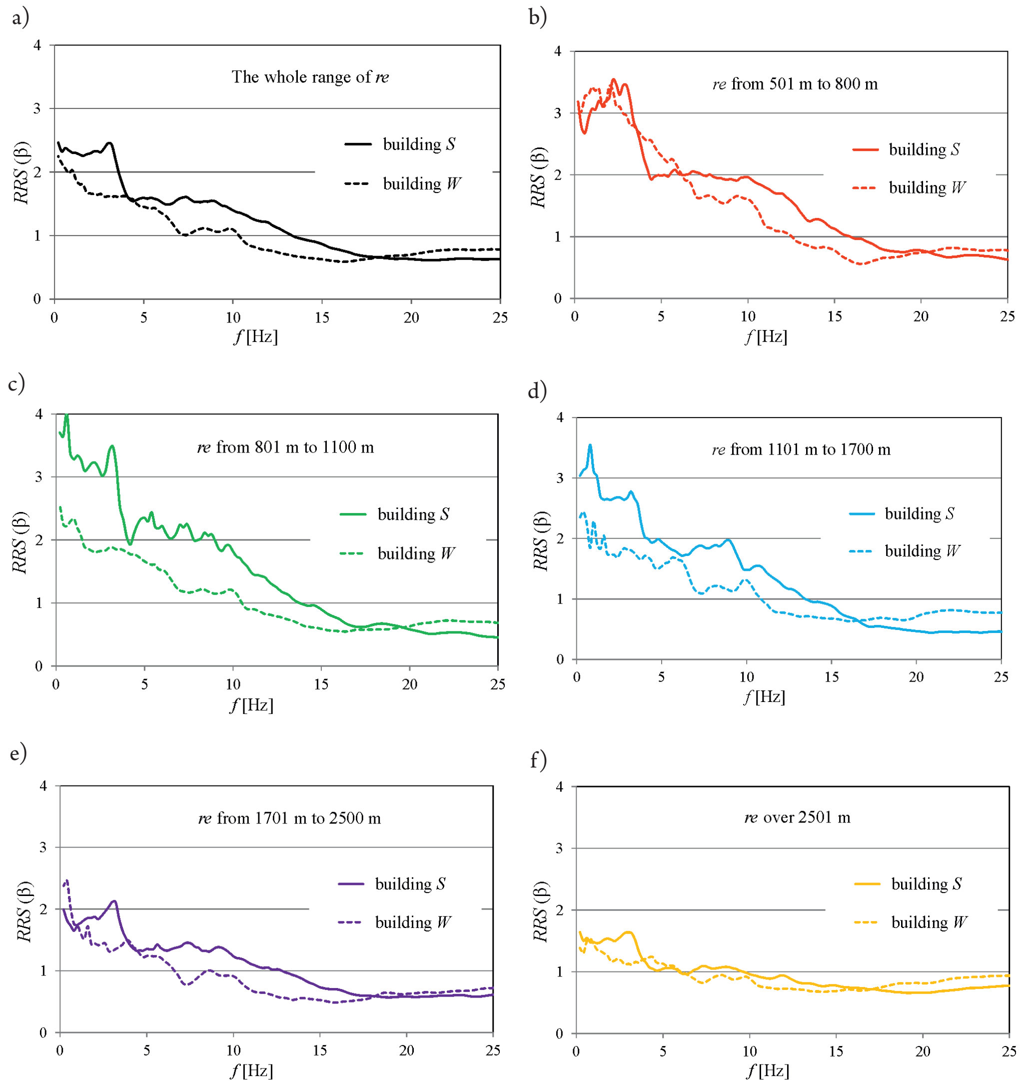

Fig. 3. Buildings *S* and *W* – relations *RRS*(β) averaged in the ranges of mining tremors epicentral distances: a) the whole range; b) from 501 m to 800 m; c) from 801 m to 1100 m; d) from 1101 m to 1700 m; e) from 1701 m to 2500 m; f) over 2501 m

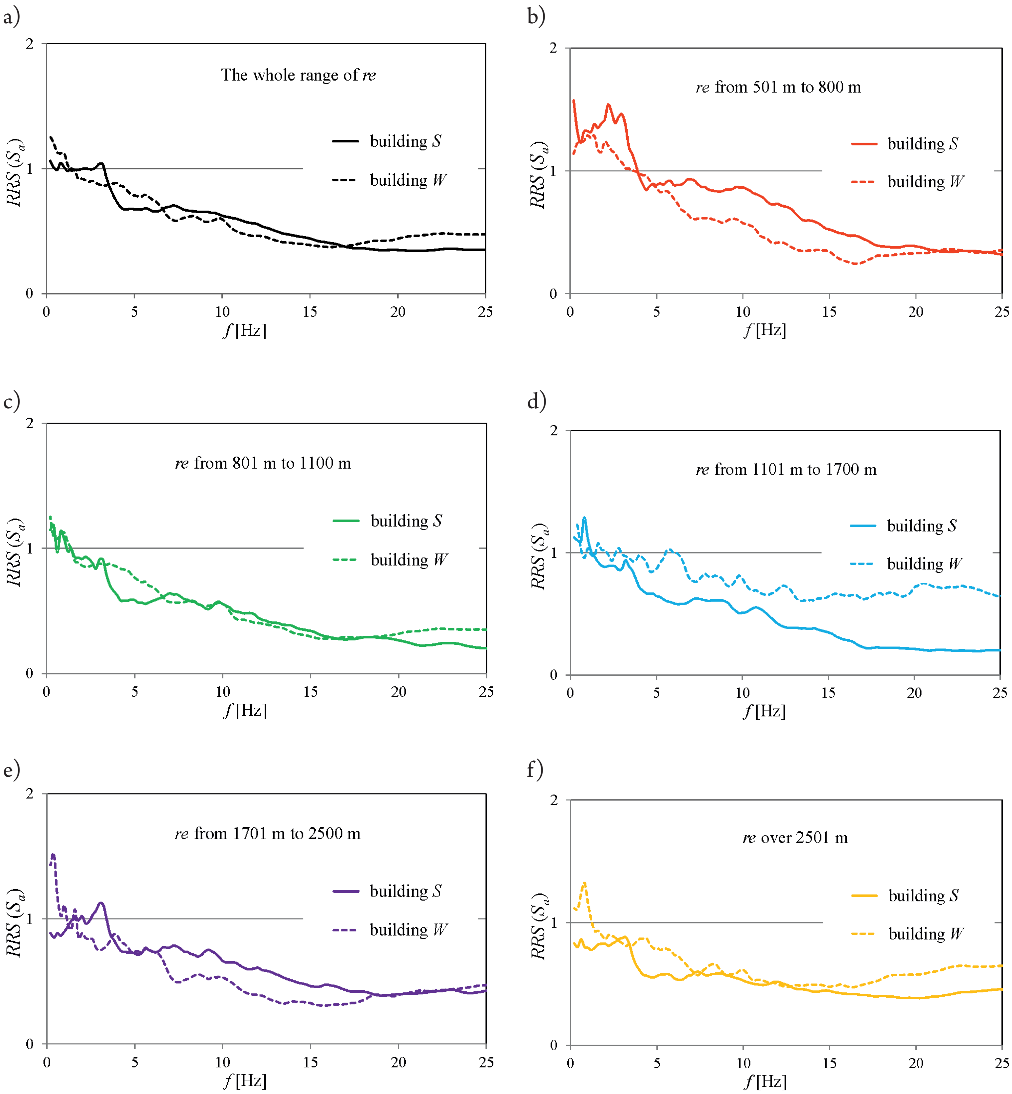

Fig. 4. Buildings *S* and *W* – relations $RRS(S_a)$ averaged in the ranges of mining tremors epicentral distances: a) the whole range; b) from 501 m to 800 m; c) from 801 m to 1100 m; d) from 1101 m to 1700 m; e) from 1701 m to 2500 m; f) over 2501 m

It is interesting to compare the results of the analysis of the influence of the epicentral distance on the relations *RRS* of response spectra from both the measured vibrations of the free-field and the building foundations with similar studies referring the different way of evaluating the transition of vibrations from ground to the building foundation. This way corresponds to reducing the maximum value of vibration acceleration in transition from free-field on the building foundations. This approach was used to elaborate measurements of vibrations in LGCD and presented in paper [9].

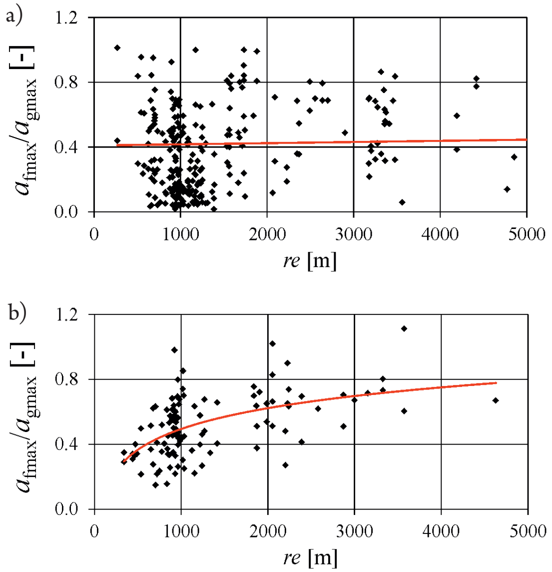

Fig. 5. Ratios a_{fmax}/a_{gmax} versus epicentral distances (*re*) in the case of buildings: a) *S*; b) *W*

Fig. 5 shows the fractions a_{fmax}/a_{gmax} (a_{fmax}, a_{gmax} – maximum value of the foundation and ground vibration acceleration, respectively) versus epicentral distance (*re*) in the case of medium-rise building *S* (Fig. 5a) and high-rise building W (Fig. 5b). While it may be found the growth in the values of those fractions with an increase in epicentral distances in the relation to the high-rise building *W*, in the case of the medium-rise building S the range of fractions a_{fmax}/a_{gmax} in successive ranges of epicentral distances is similar. This is confirmed by the trend lines shown in Fig. 5. Thus, it is different than in the relationship *RRS* in which this dependence of curves *RRS*(β) and *RRS*(Sa) on epicentral distances is clearly visible.

4. Conclusions

Analyses show that the epicentral distance of mining shocks can have a significant impact on the transmission of response spectra from the free-field to the foundations of medium-rise and high-rise buildings. This effect is more visible in the case of curves *RRS*(β) determined using dimensionless acceleration response spectra β than in the case of curves *RRS*(S_a) calculated for corresponding pairs of dimensional spectra Sa. No significant effect of the type of building structure on the differences in the relationship *RRS*(β) and *RRS*(S_a) in the individual ranges of epicentral distance is observed. Taking into account the epicentral distance of mining shock in assessing the transmission of the free-field vibrations to the building foundations has a much greater impact on the outcome of this assessment in the examination of relationships' appropriate response spectra than the maximum value of vibration acceleration.

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