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ASSESSMENT OF MINING TREMOR INFLUENCE ON THE TECHNICAL WEAR OF BUILDING

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ABSTRACT
The paper presents an analysis of mining tremor influence on the technical wear of buildings in Legnica-Głogów Copper District. The introduced index of this influence, accounts for both the intensity and number of tremors, which affected objects throughout the whole period of their lifetime. Results of the investigations for 351 traditionally structured buildings are also presented.

KEYWORDS: mining tremors, mining effects, technical wear of buildings, building damage

1. INTRODUCTION

The basic mining impact on the surface structures in the Legnica-Głogow Copper District (LGOM) are mining tremors, which cause damaging vibrations of the buildings. Apart from the mining tremor influence on the building safety, which has been widely discussed elsewhere, one should also consider the effect of the tremors on accelerating the technical wear of buildings. This type of impact should be taken into consideration both when determining the causes of damage to buildings, and when assessing costs of the mining damage. The basic parameter determining the hazard to a building safety is the peak acceleration of vibration. Consequently, the analysis does not account for the repetitiveness of tremors affecting the building. This repetitiveness can be neglected to a certain degree when analysing the safety of a building, but must be considered in any analysis of the effect of tremors on technical wear.

The paper presents a method for establishing indices that represent the impact of mining tremors on technical wear of building. On the basis of data concerning the technical condition of the traditional building development of LGOM and the mining tremors occurring there, the index a_{sg} was established, which represents an aggregated impact of seismic events that affect an object through its whole life-period. Moreover, the paper presents the results of research carried out on a group of 351 traditionally structured brick buildings located in the town of Polkowice.

2. STUDIED DATA AND A METHOD FOR DETERMINING THE TECHNICAL WEAR OF BUILDINGS

The research was carried out on a group of traditional brick, residential buildings from LGOM. Altogether, the database contains information concerning the structure, damage and technical condition of 724 objects. Out of this group, 351 buildings are located in the town Polkowice and 373 are situated in rural or suburban areas. A detailed inventory control provided information about the structure, technical state and damages of the buildings. Moreover, data regarding repairs, renovations and reconstructions were collected. A detailed inventory control of damages was performed, the technical condition and age of the damages was determined and data was collected concerning the history of damages, repair work, modernisation, reinforcements etc. Furthermore, by means of the method described below for each building the indices were determined characterising its technical condition, i.e. the degree of technical wear, s_z and its constituents: the degree of usual wear, s_n, the degree of damage, s_u

The main component of technical wear, s_z, is usual wear connected with the ageing process of building materials in specified environmental and operational conditions. Conversely, there exist a number of additional random factors, which cause damage or accelerate the technical wear. The factors can affect the whole structure or only some of its elements, also the duration of this impact can vary. An example of a factor responsible for damage can be the impact of mining exploitation, both in the form of surface deformation and strong mining tremors. Besides, one should also mention the design and implementation errors, overload of structural elements, other dynamic impacts (traffic vibrations or vibrations caused by machinery), changes of ground water level, mass wasting, etc.

Mining tremors can cause damage to elements of a building and accelerate its usual wear. An assessment of the technical condition of a building should therefore take into account factors describing both these phenomena. This demand is fulfilled by an assessment method presented by Wodyński and Kocot (1996) and verified through research described in papers of Wodyński and Barycz (2002), Wodyński and Kocot (2000), Wodyński and Lasocki (2002). In this method the technical wear of a building is split into a sum of two constituents:

$$s_z = s_n' + s_u, \tag{2.1}$$

where $s_n' = (s_n + \Delta s_n)$ is the degree of usual wear of a building, excluding damage to structural elements, connected mainly with service-life in specified environmental and operational conditions, Δs_n is the increase in usual wear connected with the effect of random factors, and s_u is the degree of damage to structural elements of a building connected mainly with the influence of additional factors, which are random in the statistical sense.

It can therefore be assumed coarsely that the impact of mining tremors on damage to structural elements of a building is represented by s_u, whereas long-lasting impact of low-intensity tremors is reflected by Δs_n.

In order to evaluate the degree of wear of a building the so-called weighted average method was employed. The method consists in an individual assessment of the degree of wear of particular elements, assigning appropriate weights to those elements and then determining the average-weighted degree of wear of the entire building

$$s_z = \sum_{i=1}^{n} \frac{u_i \cdot s_{ei}}{100}, \ [\%] \tag{2.2}$$

where u_i is the participation, expressed in percentages, of the reconstruction costs of a particular element in the reconstruction cost of the whole object and serves as a weight, and s_{ei} is the degree of wear of a given element, in per-cents.

The degree of damage s_u was determined on the basis of criteria described by Wodyński and Kocot (1986).

3. PARAMETRIC REPRESENTATION OF THE MINING TREMORS IMPACT ON THE TECHNICAL WEAR OF BUILDINGS

3.1. *INTRODUCTORY REMARKS*

In the work of Wodyński and Lasocki (2002) a twofold mining tremors effect on the technical condition of the building of LGOM was considered. The first one was the impact that posed hazard to the structure safety. This influence is linked to the strongest ground motion affecting a given object. The second type of impact does not pose hazard to the structure safety but causes damage and accelerates the wear of buildings. Since in this case the repetitiveness of dynamic impact plays the major role, the overall seismic activity, which affected a building throughout its life-period, needs to be taken into account.

Such an approach to the evaluation of impact accelerating the wear of an object often involves the whole seismic history of the thirty years of mining exploitation in LGOM. The only presently available information on this history are the mining seismic catalogs. The catalogs contain routinely: the time of event occurrence, the epicentral coordinates and the source seismic energy. The strength of ground motion caused by a tremor at the location of a particular building can be estimated using statistical relations between the seismic source parameters and the epicentral distance, and a parameterization of the ground motion. The so-far determined attenuation relations of this kind parameterize the ground motion with some peak acceleration. Consequently, the aggregated impact of tremors on a given object can at best be represented as a combination of estimated peak accelerations attributed to selected tremors. Due to the fact that intensity of ground motion depends not only on peak values but also on other parameters of vibrations, such an approach is useful only in relation to a statistical group of objects. If this approach were used to evaluate the damaging impact on a selected individual object, the results might not be reliable.

In the above cited papers it was suggested that the index of dynamic impact accelerating the wear of an object should be the geometric sum of tremor induced peak ground accelerations (PGA) at the site of the building's place. Only those tremors are taken into account, which occurred during the service life of the object and whose PGA values at the building's location are larger than a certain pre-determined threshold value a_p. For an object located at a place with the coordinates (x,y) the index will be the following:

$$a_{sg}(x,y) = \sqrt{\sum_{k=1}^{n} a_k(x,y)^2}\,; \quad a_k(x,y) \geq a_p \tag{3.1}$$

where $a_k(x,y)$ is the PGA from the tremor, estimated for the point (x,y), and n is the number of tremors that occurred during the service life and for which the estimated PGA in (x,y) was greater than the threshold value, a_p. It is supposed that a_{sg} represents the net seismic impact on the object.

3.2. *DETERMINING THE THRESHOLD VALUE a_p*

Wodyński and Lasocki (2002) used preliminarily two values of the threshold a_p., namely 0.02 m/s^2 and 0.12 m/s^2. In spite of some randomness of this choice, correlation tests carried out on a group of 1021 buildings showed that this type of index can account for the tremor impact on accelerating the technical wear of buildings. In particular a_{sg} determined with the threshold value $a_p = 0.02$ m/s^2 correlated with usual wear s_n and technical wear s_z.

In the present work a detailed analysis was carried out of the influence of the threshold value a_p on the degree of correlation between the index a_{sg} and indices representing usual wear s_n, degree of damage s_u and technical wear s_z. The purpose of this analysis was to select a threshold value a_p for which the relationship between a_{sg}, and the indices reflecting the condition of a building would be the strongest.

When changing the threshold, a_p, the degree of correlation of dynamic impact index, a_{sg}, with the indices representing the condition of a building varies in a complex way. For low values of a_p the impacts of the majority of occurring tremors are summed and a_{sg} is linked to the number of tremors which occurred during the service life of an object, i.e. to the duration of service life. Since the condition of a building depends mainly on its service life, the correlation between a_{sg} and the indices of technical condition of the building (s_u, s_n' and s_z) reflects, in this case, the deterioration of the condition of an object connected with the passage of time rather than represents the influence of the repeated tremor impact. Being such the correlation is obviously strong. As the threshold value a_p increases, the influence of service life is less conducted by a_{sg} and the correlation will decrease. This is due to the fact that the number of high-intensity tremors depends more on the location of a building than on its service life. A next increase of the correlation with rising a_p will mean that PGA-s for evaluating a_{sg} in (3.1) were more properly selected, that is they represent ground motions which actually had impact on buildings. The threshold value for which the strength of the correlation again becomes maximum provides an optimal choice of a_p for estimating the dynamic impact by means of the index a_{sg}.

Although it is unimportant which attenuation relation of peak acceleration will be used to determine the index asg, the optimum threshold value, a_p, is different for different attenuation relations.

Wodyński and Lasocki (2002) used the following formula to establish the values of $a_k(x,y)$ (Speczik et al. 2003):

$$\log a(x,y) = -0.46 + 0.225 \log E - 0.614 \log r\,, \tag{3.2}$$

where $a(x,y)$ is the peak acceleration of ground motion in the frequency band up to 10Hz in [m/s^2], E is the source seismic energy of the tremor in [J], and r is the distance between the event epicenter and the point (x,y) in [m]. The relation, developed on the basis of data from the range of $E \in [10^6,\ 2.5\times10^9]$, $r \in [300,\ 8700]$, is supposed to be suitable for the whole area of LGOM.

The relation (3.2) is linear with regard to the logarithm of epicentral distance and therefore not applicable to determining PGA in the epicentral area. A considerable part of the analysed database of LGOM contains information about buildings for which the epicentral distances from some tremors were very short. This is particularly the case with the building of Polkowice. Wodyński and Lasocki (2002) passed by the problem connected with small r removing from the analysis objects located nearer than 200 m from the source. The same trick used in the present study would exclude from further research about 300 out of 351 buildings listed in the inventory. Besides losing the number, the analysis would not take into account the objects, which were potentially the most exposed to seismic impact.

Lasocki (2002) provides a new, non-linear attenuation relation

$$\log a_H(x,y) = 0.388 + 0.29 \log E - 1.049 \log \sqrt{r^2 + (812)^2} \tag{3.3}$$

where $a_H(x,y)$ is the peak horizontal component of acceleration of ground motion in the frequency band up to 10 Hz in [m/s^2], E is the source seismic energy of the tremor in [J], and r is the distance between the event epicenter and the point (x,y) in [m].

The relation (3.3) was developed on the basis of data concerning tremors in the Polkowice area. The relation is non-linear and applicable to all epicentral distances up to 10000 m. The energy of tremors which were taken into consideration when identifying the relation (3.3) ranged from 5×10^3J up to 2.5×10^9J. Since the relation is connected with the Polkowice area it was used only for objects whose coordinate x was not less than 30000 (in the seismological system).

For buildings with the coordinate x < 30000 we used a formula developed in the Department of Geophysics of the AGH University of Science and Technology:

$$\log a_H(x,y) = -0.667 + 0.263 \log E - 0.725 \log r\,, \tag{3.4}$$

where $a_H(x,y)$ is the peak horizontal component of acceleration of ground motion in [m/s^2], E is the source seismic energy of the tremor in [J], and r is the distance between the event epicenter and the point (x,y) in [m]. The relation was developed on the basis of data concerning tremors in the area of town Lubin. Like (3.2), the relation (3.4) is also linear with the logarithm of epicentral distance and cannot be applied for small epicentral distances. The use of this relation was therefore limited to r larger than 200 m. The reason why relation (3.4) and not (3.2) was applied when evaluating the seismic impact on buildings with the coordinate x < 30000 was the fact that in relation (3.4) the dependant variable is, as in relation (3.3), the peak horizontal component of acceleration, whereas in relation (3.2) the dependant variable is the peak value of total acceleration.

The investigations for establishing the optimal threshold value a_p were performed on a separated group of 281 buildings which had not undergone any significant repair or reconstruction. In order to determine the seismic impacts the whole available information concerning tremors in LGOM was used. The major source of the data were seismic catalogs of particular mines of the KGHM „Polska Miedź" S.A. The catalogs comprise the following periods:

- 14.12.1975 – 15.03.2003 - catalog of the Polkowice-Sieroszowice mine
- 1.01.1987 – 31.03.2003 – catalog of the Lubin mine
- 21.03.1980 – 15.03.2003 – catalog of the Rudna mine

Data from the catalogs were completed by the information concerning high-intensity tremors which had occurred before the periods mentioned above. In order to analyse the impact on the studied buildings only those tremors were taken into account whose energy was greater than 10^4J. Altogether 18 921 tremors were used in the analysis.

For a given a_p value the index a_{sg} and the number of tremors which were used to evaluate a_{sg} were calculated for each building. The latter value was denoted as n_{sg}. Subsequently, the non-parametric correlation gamma coefficients: $\gamma(a_{sg}, s_u)$, $\gamma(n_{sg}, s_u)$, $\gamma(a_{sg}, s_z)$, $\gamma(n_{sg}, s_z)$, $\gamma(a_{sg}, s_n')$, $\gamma(n_{sg}, s_n')$ were evaluated. The non-parametric instead of Pearson's correlation coefficient was applied because the distribution of indices characterising the technical condition of a building considerably deviates from the normal distribution. The choice of gamma correlation was in turn dictated by the frequent repetition of indices values for different buildings. If the values of correlated random variable recur it is advisable to use this particular rank order correlation coefficient.

The obtained results of the correlation analysis for different threshold values, a_p, are given in Table 3.1. The number of pairs of correlated values equals the number of buildings for which it was possible to establish the value of a_{sg} other than zero. Italic font was used to mark the values of correlation coefficient significant at 95 per cent confidence.

When going through the results presented in the above Table one should remember about the bias of the correlation coefficient estimator. As a result of the estimator bias, for the same significance of relationship between two variables, the value of the correlation coefficient grows as the sample size decreases. Therefore the relationship is the strongest when it has the largest significance.

From Table 3.1 it follows that the optimum threshold value, a_p, is about 0.12 m/s^2. To make this estimation more precise the analysis was repeated for threshold values changing every 0.01 m/s^2. The results are given in Table 3.2.

Table 3.1 Results of analysis of correlation between the dynamic impact indices and the indices representing the technical condition of a building - part I

a_p [m/s^2]	No of pairs for correlation	$\gamma(a_{sg}, s_u)$	$\gamma(n_{sg}, s_u)$	$\gamma(a_{sg}, s_z)$	$\gamma(n_{sg}, s_z)$	$\gamma(a_{sg}, s_n')$	$\gamma(n_{sg}, s_n')$
0.02	277	*0.262*	*0.300*	*0.216*	*0.263*	*0.172*	*0.221*
0.05	270	*0.128*	*0.140*	0.062	0.077	0.014	0.029
0.08	192	0.100	*0.158*	0.019	0.070	-0.045	-0.005
0.12	62	*0.430*	*0.447*	*0.403*	*0.377*	*0.350*	*0.304*
0.16	49	0.194	*0.470*	0.180	0.284	0.095	0.137
0.20	44	0.119	*0.395*	0.105	0.201	0.046	0.082
0.25	16	0.362	*0.600*	0.111	0.316	-0.043	0.075
0.30	8	-0.071	-0.143	0.037	0.100	0.143	0.429

Table 3.2 Results of analysis of correlation between the dynamic impact indices and the indices representing the technical condition of a building - part II

a_p [m/s^2]	$\gamma(a_{sg}, s_u)$	$\gamma(n_{sg}, s_u)$	$\gamma(a_{sg}, s_z)$	$\gamma(n_{sg}, s_z)$	$\gamma(a_{sg}, s_n')$	$\gamma(n_{sg}, s_n')$
0.08	0.100	*0.158*	0.019	0.070	-0.045	-0.005
0.09	*0.173*	*0.246*	*0.127*	*0.212*	0.072	*0.153*
0.10	*0.285*	*0.346*	*0.243*	*0.341*	*0.197*	*0.282*
0.11	*0.400*	*0.410*	*0.345*	*0.338*	*0.284*	*0.252*
0.12	*0.430*	*0.447*	*0.403*	*0.377*	*0.350*	*0.304*
0.13	*0.263*	*0.341*	*0.265*	*0.242*	0.178	0.150
0.15	*0.211*	*0.481*	*0.215*	*0.308*	0.133	0.165

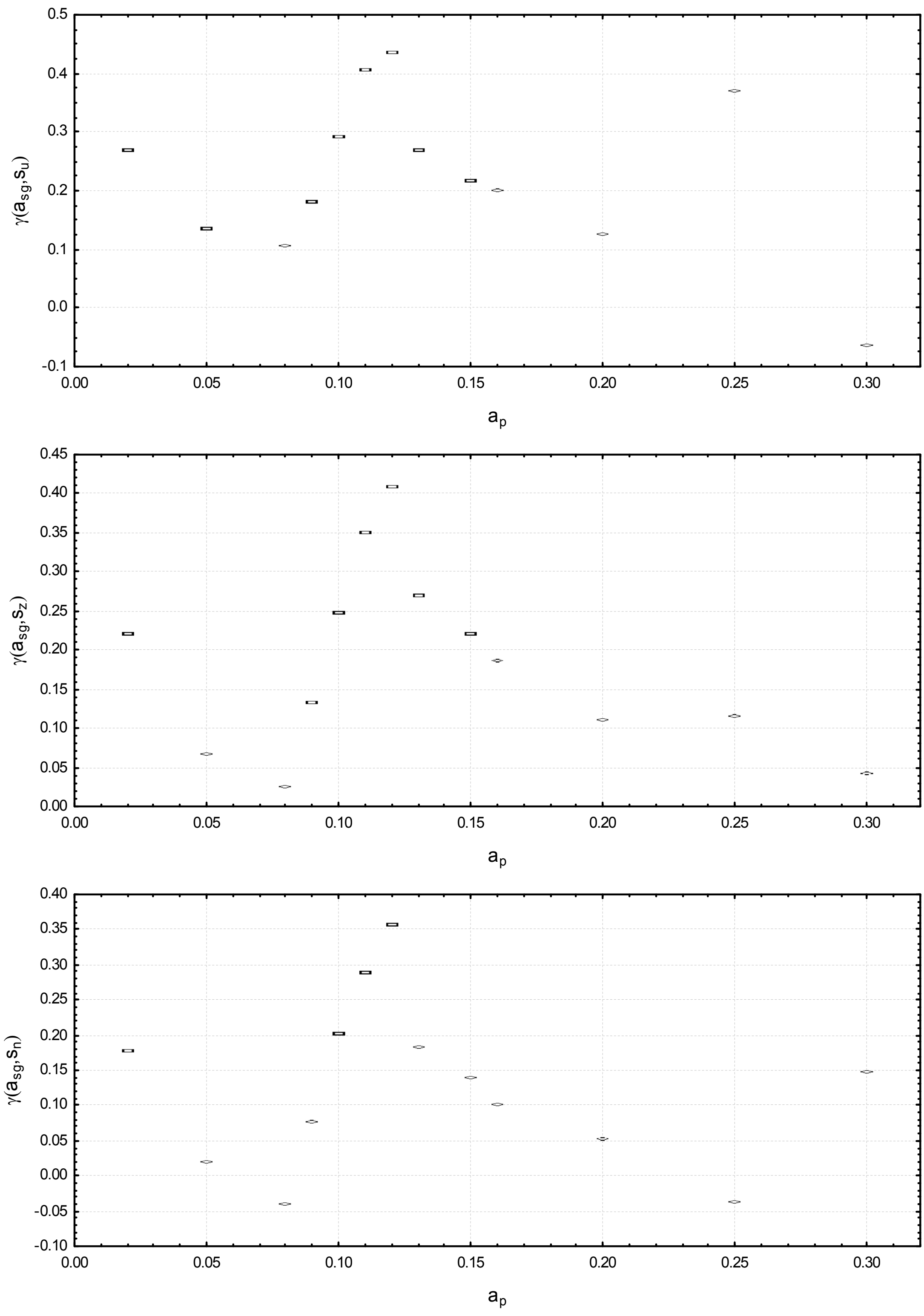

Fig. 3.1 Variations the correlation coefficient of seismic impact index and the indices representing technical condition of a building (s_u, s_z, s_n') with the threshold value. Squares represent values significant at 95% confidence.

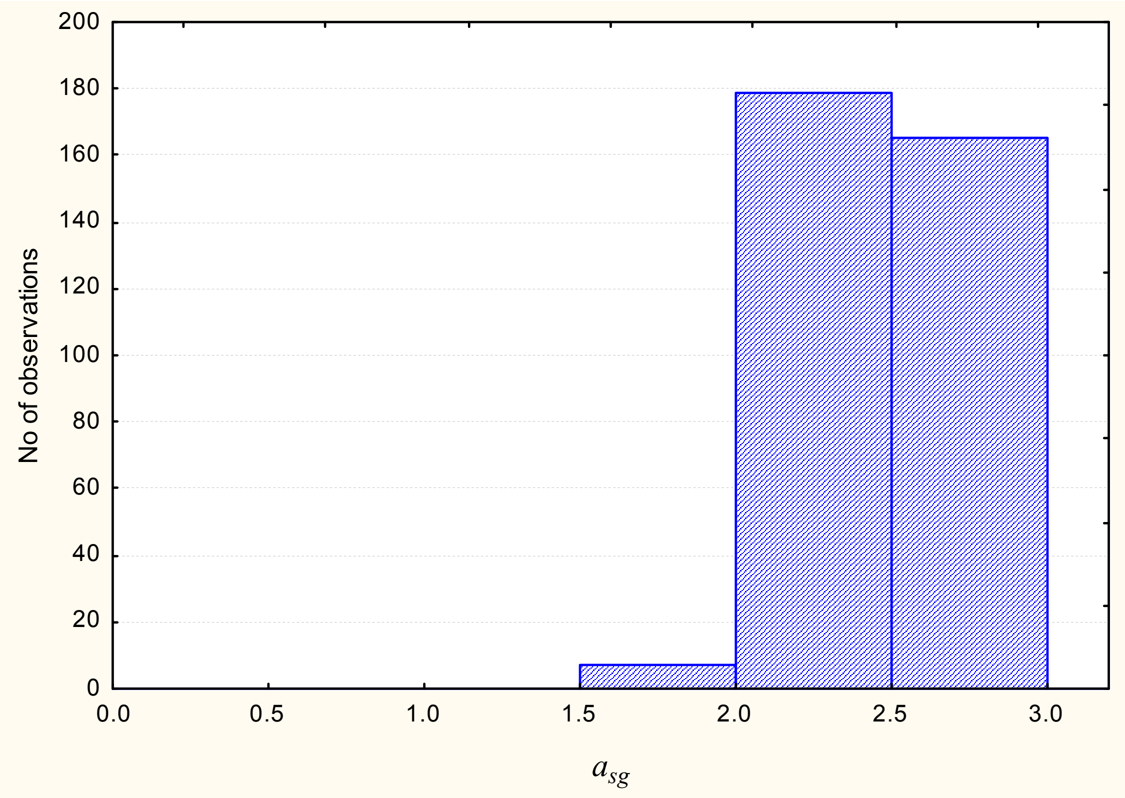

Fig. 3.2 Distribution of non-zero values of the dynamic impact index a_{sg} in the analysed group of buildings located in Polkowice (351 objects)

The results presented in the Tables ascertain that a_p = 0.12 m/s^2 is the optimal threshold value for estimating the repetitive seismic impact accelerating the wear of the analysed buildings by means of the index a_{sg}. It has to be stressed, however, that this value is connected with attenuation relations (3.3) and (3.4) used in the present study. If other attenuation relations were used, the search for the optimal threshold value would have to be repeated.

Figure 3.1 presents the variations of the coefficients of rank correlation between the index a_{sg} and the indices s_u, s_z and s_n', which take place as the threshold value, a_p, increases. Correlations significant at 95 per cent confidence were marked with squares. For all three cases considered here the maximum correlation coefficient was observed for the threshold value a_p = 0.12 m/s^2.

3.3. DETERMINING THE INDEX a_{sg} FOR ALL STUDIED BUILDINGS

On the basis of the seismic catalogs mentioned earlier in this work and taking into account the conclusions made above the value of the index a_{sg} was evaluated for all 724 residential buildings listed in the database concerning the studied building development. For 453 buildings, including all 351 buildings located in Polkowice, the dynamic impact index was greater than 0. The distribution of non-zero values of dynamic impact index a_{sg} in this group is given in Figure 3.2. It can be observed that a_{sg} ranges 2.0 to 3.0 for most of the studied objects.

4. CORRELATIONS BETWEEN THE INDICES CHARACTERISING THE TECHNICAL WEAR AND THE SEISMIC IMPACT INDEX

Further studies concerned the relationships between the degree of technical wear s_z estimated during the inventory control of a building and its constituents i.e. degree of damage s_u and the usual wear s_n' (see: Chapter 2), and the index a_{sg} (Chapter 3). The analysis was carried out on a group of 351 traditionally structured buildings located in Polkowice, for which the index $a_{sg} > 0$.

For reasons discussed in Chapter 3 the analysis of the dependence between the examined variables made use of the gamma correlation coefficient. Although the mentioned in Chapter 3 problem concerning the distribution of indices characterising the condition of a building is mainly limited to the degree of damage s_u, for the purpose of a greater coherence of the study the same non-parametric correlation analysis was done for all indices.

In every case the correlation coefficient γ and the level of significance of correlation, p, was estimated. Usually p = 0.05 is taken as a critical level. This means that the obtained correlation coefficient γ can be recognised as significant only for the level $p < 0.05$.

Table 4.1 Analysis of correlation between the degree of wear s_z, degree of damage s_u and usual wear s_n', and the index a_{sg} representing mining tremor impact for a group of 351 buildings located in Polkowice

studied group of buildings [number of obects]	s_z		s_u		s_n'	
	correlation coefficient γ	significance level p	correlation coefficient γ	significance level p	correlation coefficient γ	significance level p
all buildings (351)	0.128	0.000	-	-	0.147	0.000
reinforcement provided at the construction stage (312)	-	-	-	-	-	-
reinforcement provided during service life (38)	0.242	0.043	-	-	0.284	0.013
renovated (133)	-	-	-	-	-	-
not renovated (218)	0.176	0.000	-	-	0.183	0.000

Table 4.1 presents the cases for which statistically significant, positive correlations between the analysed variables were obtained. The research was conducted on the whole group of 351 buildings and on sub-groups of buildings selected on the basis of the preventive reinforcement devices used and the performed repair work. The distinction was done between devices supplied at the stage of construction and during the service life of a building.

It can be seen in the Table that in the case of the whole group of 351 examined buildings significant correlations were obtained for the degree of technical wear s_z and the degree of usual wear s_n'. It is symptomatic that the index a_{sg}, which represents the mining tremor impact on accelerating the technical wear, shows correlation with s_n', and consequently with Δs_n. Δs_n represents the increase in wear caused by long-term influence of additional factors. This confirms the thesis that an analysis of the mining tremor impact on technical wear of buildings should take into account the repetitiveness of impact of tremors with relatively low PGA values.

In the case of buildings which were provided with preventive reinforcement devices at the stage of construction no significant correlations were detected. The results might indicate that the protection against mining impact designed for new buildings is globally effective also with regard to mining tremor impact on technical wear of buildings. In the case of older buildings, erected prior to the mining exploitation in the area, which were provided with reinforcement against mining impact already during their service life (roof bolting, reinforced concrete bands) the research showed significant correlations between the analysed variables. This result seems justified since the aim of such preventive measures is mainly the safety of using a building while allowing a certain degree of damage.

In the case of buildings which had undergone repairs no significant correlations were observed. Such correlations occurred, however, in the case of buildings which had not undergone repair. The results attest to the effectiveness of the conducted repair work in relation to the mining tremor impact on technical wear of the studied building development.

5. CONCLUSIONS

In order to assess mining tremor impact on accelerating the technical wear of building it is necessary to take into account the aggregated influence of all tremors affecting an object throughout its life-period.

Such influence was parameterised by the index a_{sg} defined as a geometric sum of PGA induced by tremors, which occurred at the location of the object. Out of all tremors that occurred during the life-period of the object only those are taken into account whose PGA-s at the location of the object are greater than a pre-determined threshold value a_p. It was ascertained that from the standpoint of estimating the repetitive seismic impact by means of the index a_{sg}, the value of a_p = 0.12 m/s^2 is the optimum threshold value for the attenuation relations of PGA used in the study.

An analysis of mining tremor impact on the technical wear s_z of the traditional building of

Polkowice, conducted on the basis of this index, showed significant correlations between the examined variables in the case of the whole group of buildings and selected sub-groups: buildings provided with preventive reinforcement during their service life and buildings which had not undergone repair. In the case of buildings which were supplied with reinforcement system during the construction process and buildings which had undergone repair no significant correlations were detected.

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