



**ASSESSMENT OF SEISMIC RESISTANCE OF SOME HISTORICAL ARCHITECTURAL  
MONUMENTS OF UZBEKISTAN**

**POSÚDENIE SEIZMICKEJ ODOLNOSTI NIEKTORÝCH HISTORICKÝCH  
ARCHITEKTONICKÝCH PAMIATOK UZBEKISTANU**

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**Abstract**

The article is devoted to the study of the seismological situation of the sites of architectural monuments Kuk Gumboz Mosque, Khuzha Ilm Koni Complex, Said Otalik Madrasah and Ishratkhona Structures in Central and Southern Uzbekistan, as well as their seismic resistance. In its structural position, this territory belongs to the area of the transition from the Tien Shan epiplatform orogen to the Turan platform, its seismicity is directly related to the tectonic structure of the region and manifests itself mainly within the large faults of the earth's crust, activated at the present stage of geological development. Areas of active dynamic influence of these faults are identified (Ibragimov et al., 2002) in seismogenerating zones.

**Abstrakt**

Článok je venovaný štúdiu seizmologickej situácie lokalít architektonických pamiatok Mešity Kuka Gumboza, komplexu Khuzha Ilm Koni, štruktúr Said Otalik Madrasah a Ishratkhona v strednom a južnom Uzbekistane, ako aj ich seizmickej odolnosti. Svojou štruktúrnou polohou patrí toto územie do oblasti prechodu od epiplatformného orogénu Tien Shan k platforme Turan, jeho seizmicita priamo súvisí s tektonickou štruktúrou regiónu a prejavuje sa najmä v rámci veľkých zlomov zemskej kôry, aktivovaných v súčasnom štádiu geologického vývoja. Oblasti aktívneho dynamického vplyvu týchto porúch sú identifikované (Ibragimov et al., 2002) v seizmogeneračných zónach.

## Keywords

*architectural monument, earthquake, PGA hazard curves*

## Klíčové slová

*archeologické památky, zemětřesení, krizové křivky PGA*

# 1. Seismicity in the vicinity of architectural monuments in the territory of Central and Southern Uzbekistan

The architectural monument Kuk Gumboz Mosque (later, for the brevity of the presentation of object 1) is located at a slight distance from the southern edge of the South Tian Shan seismogenic zone, which, according to both seismological and seismotectonic data, is characterized by a very high seismic potential ( $M_{\max} = 7.5$ ) (Ibragimov et al., 2002; Artikov et al., 2020a). The Khuzha Ilm Koni complex (object 2) is located directly within the South Tian Shan seismogenic zone. It should be noted that if the western part of the South Tien Shan seismogenic zone proved to be the three strongest platform Ghazli earthquakes 1976 and 1984 with magnitude  $M = 7.0-7.3$ . In the eastern part of this zone, where the Kuk Gumboz Mosque and the Khuzha Ilm Koni complex are located, no earthquakes of magnitude greater than 5.3 occurred during the instrumental observation period.

The Madrasah Said Otalik object (object 3) is located between the Gissar-Kokshaal and Bobatag Keikitau seismogenic zones near the meridional direction. Seismic potential of Gissaro-Kokshaal seismogenic zone is estimated by value  $M_{\max} = 7.5$ , and Bobatag-Keikitau  $M_{\max} = 6.5$ . Within the Gissar-Kokshaal seismogenic zone in 1907, two strongest Karatag earthquakes occurred with magnitudes  $M = 7.3$  and  $M = 7.4$ . To the south, the Gissar-Kokshaal zone branches into two seismoactive zones - Baysun-Kugitan and Surkhantau-Sherabad-Kelifsky. Seismic potential of these zones is estimated by value  $M_{\max} = 6.5$ .

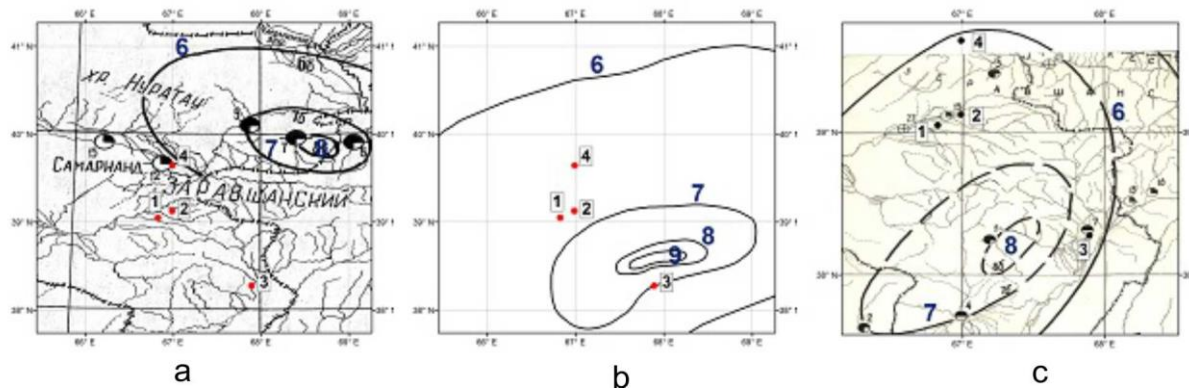
The Ishratkhona mausoleum (object 4) is located directly within the Zarafshan faults system near latitudinal extension, united in (Ibragimov et al., 2002) into the seismic-generating zone of the same name, the seismic potential of which is estimated by the value  $M_{\max} = 6.5$ . Two high-potential seismogenic zones pass to the north of the Ishratkhona mausoleum, earthquakes within which cause significant shocks at this facility. This is the North Kuljuktau-Turkestan seismogenic zone, the seismic potential of which is estimated by the value  $M_{\max} = 6.5$  and the Besapano-North Nuratinsky zone with the value  $M_{\max} = 6.5-7.0$ , which is the western continuation of the very active and highly potential South Ferghana seismic zone. Within the western part of the South Ferghana seismic zone in 1897, historical Uratubin earthquakes occurred with a magnitude of  $M = 6.6-6.7$ , which caused tangible shocks on each of the objects under consideration. Within the North Kuljuktau-Turkestan seismogenic zone in 2013, the Marjanbulak earthquake occurred with a magnitude of  $M = 6.1$ .

## 2. Seismic risk in the areas of objects

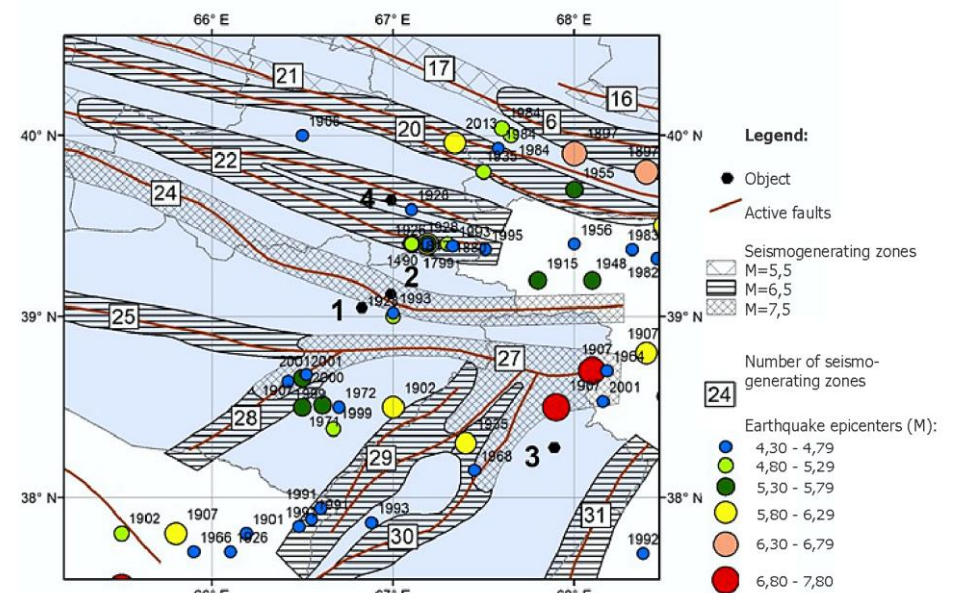
Currently, the area of the facilities is under seismic activation, as evidenced by a whole series of moderate earthquakes, the strongest of which is the Kitab earthquake of 2016 with magnitude  $M = 5.0$  and the Bakhmal earthquake of 2017 with magnitude  $M = 5.1$ .

Fig. 1 shows a map of the epicenters of tangible and strong ( $M > 4.5$ ) earthquakes that occurred during the historical period of time in the area under study. The same figure shows active faults of the Earth's crust and seismic zones isolated on their basis according to (Ibragimov et al., 2002). The numbering of seismogenic zones is adopted as in the original source (Ibragimov et al., 2002). Tab. 1 shows the parameters of earthquakes that occurred within a radius of  $R = 150$  kilometers from each object, and indicates the intensity of shocks that they caused at the object. For those seismic events whose macroseismic survey was not carried out, the seismic effect assessment was calculated based on the damping relationships of the intensity of seismic impacts with the distance set in (Artikov et al., 2020b).

Fig. 2 shows the isoseist diagrams of the three strongest earthquakes that occurred in the studied region: the Uratyube earthquake of 1896 with magnitude  $M = 6.7$ , the Karatag earthquake of 1907 with magnitude  $M = 7.3$  and the Baysun earthquake of 1935 with magnitude  $M = 6.2$ . The first of them occurred within the western segment of the South Ferghana seismic zone and had the greatest seismic impact on object 4. During the Karatag earthquake of 1907, which arose within the Gissaro-Kokshaal



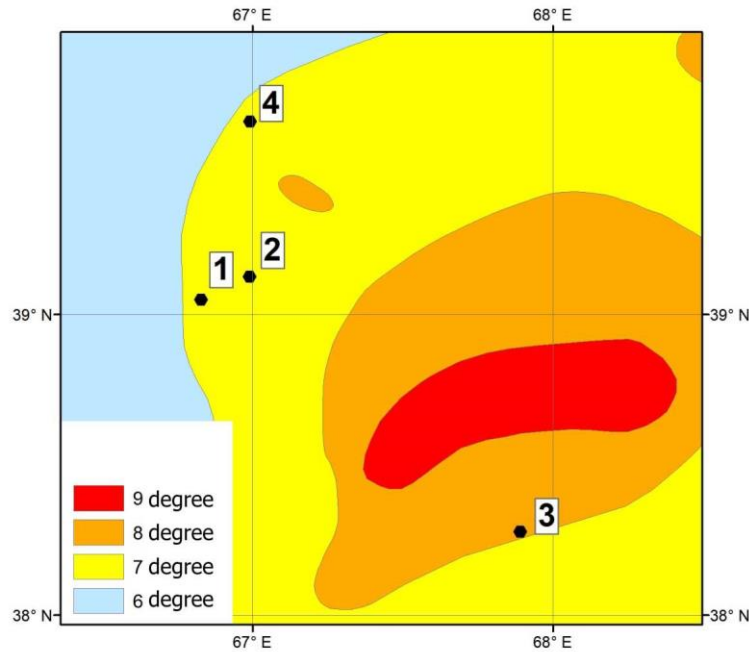
**Fig. 2 Isoseist schemes of the strongest earthquakes of the studied area:**  
**a) Uratyubinsky earthquake of 1897,  $M = 6.7$ ;**  
**b) Karatag earthquake of 1907,  $M = 7.3$ ;**  
**c) 1935 Baisun earthquake,  $M = 6.2$**



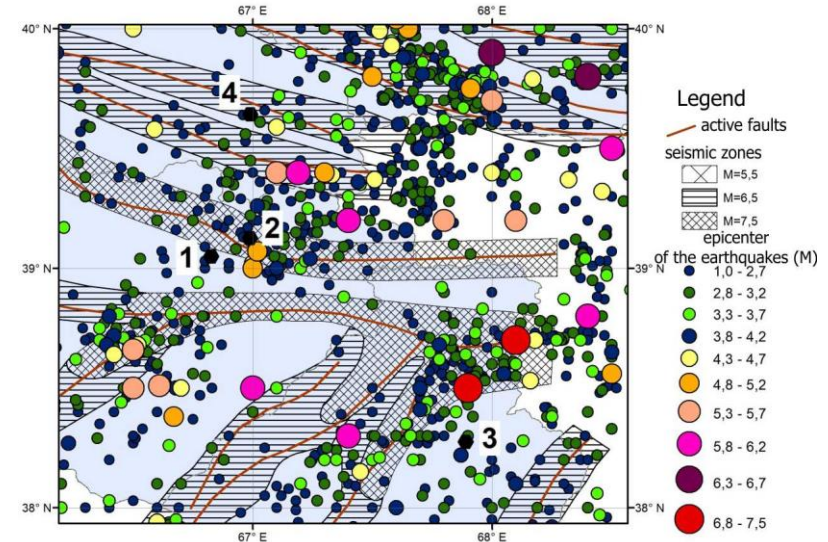
**Fig. 1 Map of epicenters of strong earthquakes from historical period of time in the vicinity of the location of objects**

seismogenerating zone, the concussion at object 3 was 8 points on the MSK- 64 scale, the remaining objects were further, for seven points of isoseist. A similar distribution of the intensity of seismic impacts was observed during the Baisun earthquake, which occurred within the Baisun-Kugitan seismogenic zone in 1935. The envelope of the maximum observed intensity line from all known shocks of the region is shown in Fig. 3.

As follows from Fig. 3, the maximum intensity of shocks from all strong earthquakes that occurred in the vicinity of objects 1, 2 and 4, according to available



**Fig. 3 Zones of maximum observed intensity of seismic impacts from all known earthquakes of historical and instrumental period**



**Fig. 4 Map of the epicenters of instrumental and historical earthquakes until 2020**

macro-seismic data, did not exceed 7 points on the MSK-64 scale. For object 3, the maximum intensity of concussions was 8 points on the MSK-64 scale.

The system of instrumental seismometric observations surrounding objects 1–4 includes a network of regional stations providing representative registration of earthquakes of the 9th energy level ( $M = 2.5$ ). The closest seismic stations to the objects are Pachkamar, Zarabag, Agalyk, Samarkand, Jizak. A map of the epicenters of earthquakes recorded during the instrumental and historical time period is shown in Figure 4.

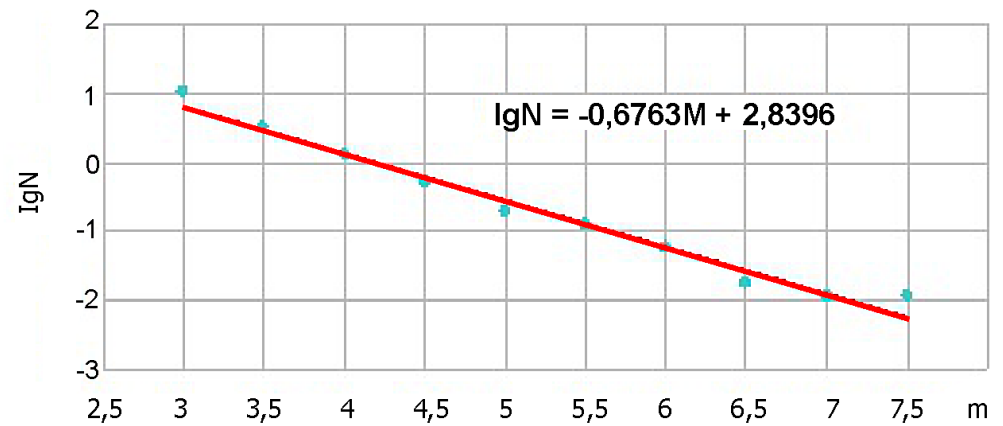
It clearly shows that small-magnitude earthquakes are randomly located within the studied region, and strong earthquakes are mainly confined to the previously listed seismogenic zones. The largest density of local epicenters is characterized by the vicinity of site 2, the smallest - site 4. The overwhelming number of recorded earthquakes is located in the seismoactive layer of the earth's crust, the thickness of which in this area is 25–30 kilometers.

In order to obtain quantitative characteristics of seismicity of the entire area under study and vicinity of sites of 1–4 objects location according to the catalog filtered from aftershocks, earthquake recurrence graphs were constructed. With magnitude classification of

earthquakes by magnitude, the Gutenberg-Richter dependence, which connects the number of earthquakes of various magnitude  $N_M$  level with magnitude  $M$ , has the form:  $LgN_M = a - bM$

Fig. 5 shows a graph of the recurrence of representative earthquakes of different magnitudes (Gutenberg-Richter dependence) for the entire study area shown in Fig. 4, and Tab. 2 shows the average periods of repetition of earthquakes of different magnitude level, obtained from this graph.

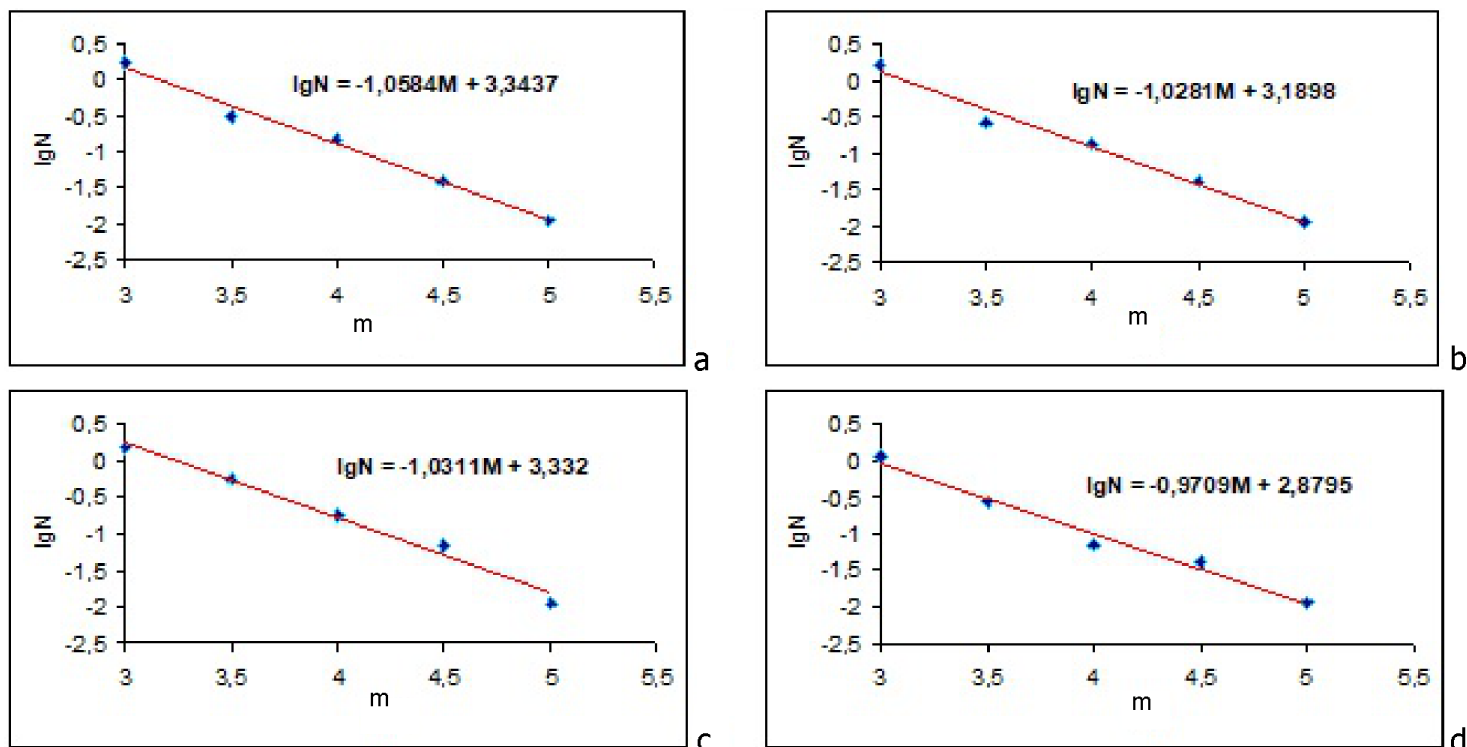
The following figure (Fig. 6) shows the repeatability graphs and shows the Gutenberg-Richter dependencies for the local 150 kilometer surroundings of each object. Constructions are made for earthquakes in the magnitude range from  $M = 3.0$  to  $M = 5.0$  with a gradation of  $0.5 M$ . As follows from these graphs, both the angular coefficients of these lines and their level, which determines the seismic activity of the local vicinity of the sites, do not differ significantly. The exception is the site of object 4, for which these parameters are lower than in other sites.



**Fig. 5 Diagram of recurrence earthquakes in the area under investigation**

**Tab. 1 Average period of repetition (T) of earthquakes of various magnitudes (M) in the studied area of historical monuments location**

M	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
T	2 month	4 month	9 month	1.5 -2 year	3-4 year	7-8 year	15-17 year	35-40 year	80-90 year	150-200 year

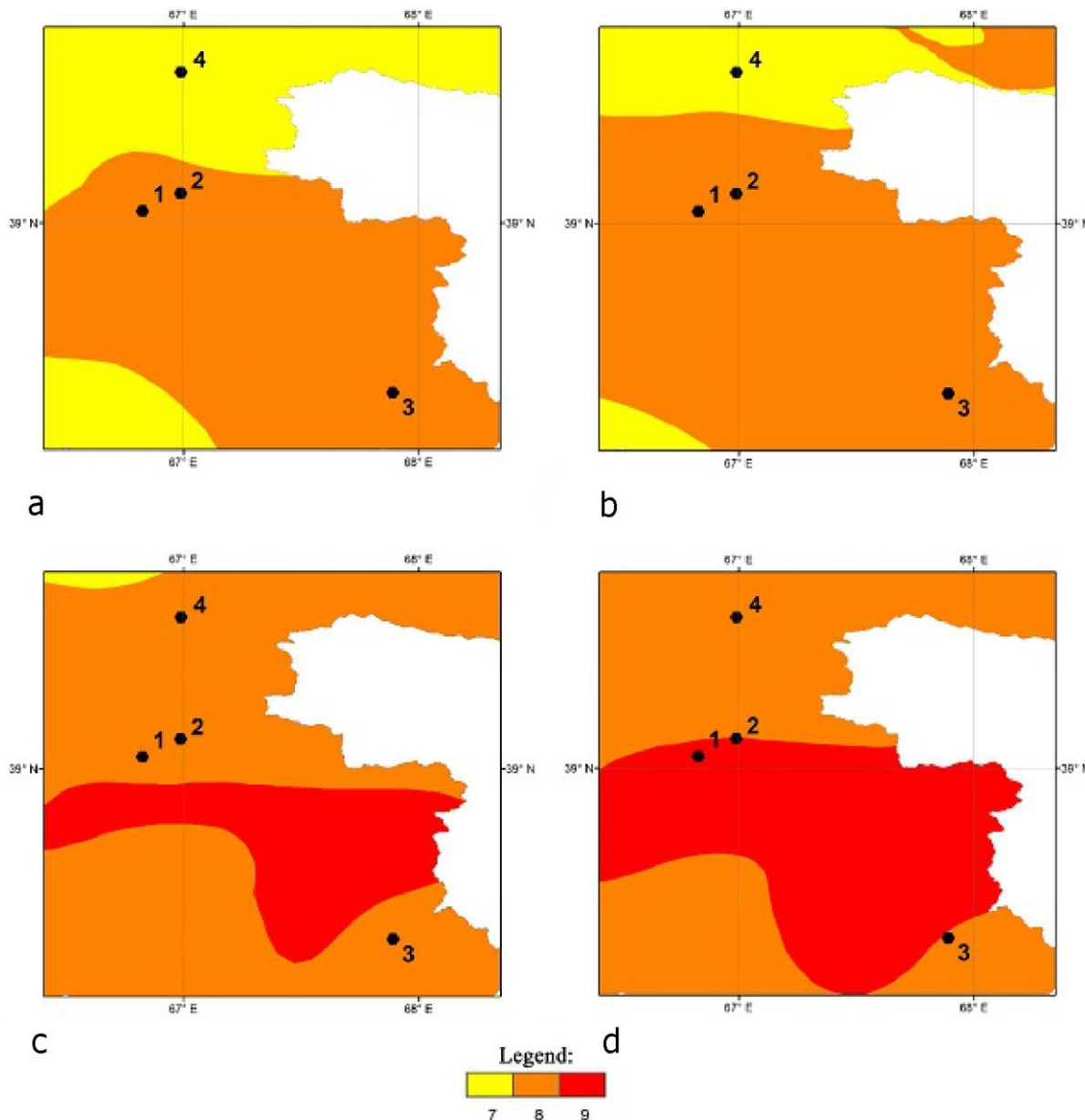


**Fig. 6** Frequency graphs of earthquakes that occurred in the local 150 kilometer neighborhood: a) object 1; b) object 2; c) object 3; d) object 4

According to the current maps of the total seismic zoning of the territory of Uzbekistan OSR-2017 (Artikov et al., 2020a), for various probabilities not exceeding the intensity of seismic impact for 50 years (Fig. 7), objects 1–4 belong to the following zones of macro-seismic intensity (Tab. 2). In macro-seismic scale scores are built for average ground conditions, to which soils of the second category are assigned on the territory of Uzbekistan by seismic properties. Local soil conditions of sites occupied by objects can give both positive and negative increments of intensity.

**Tab. 2** Macro-seismic probability of objects 1–4 according to maps OSR-2017 for different probabilities not exceeding the level of seismic impact for 50 years (for average ground conditions)

Object	Macro-seismic probability of objects			
	$P=0.9$	$P=0.95$	$P=0.98$	$P=0.99$
	degree			
1	8	8	8	9
2	8	8	8	9
3	8	8	8	8
4	7	7	7	7



**Fig. 7** Fragments of seismic zoning maps of the territory of Uzbekistan OSR-2017 indicating the locations of objects for various probabilities  $P$  not exceeding the level of seismic impact for 50 years:  
 a)  $P = 0.9$ ; b)  $P = 0.95$ ; c)  $P = 0.98$ ; d)  $P = 0.99$

Taking into account the long-term parameters of the seismic mode and the laws of attenuation of the intensity of seismic impacts with distance, periods of repetition of shocks of various intensities were calculated for the territories of the sites of the investigated objects. Fig. 8 (a - d) show fragments of maps of periods of concussion repetition with intensity  $I = 6, I = 7, I = 8$  and  $I = 9$  points. The numerical values of these concussion are summarized in Tab. 3.

To study the seismic hazard of the facility area in terms of engineering characteristics of seismic impacts, values of maximum accelerations PGA and spectral amplitudes of accelerations PSA for periods of seismic oscillations from 0.05 to 3 seconds were calculated for each of the four sites of the facilities

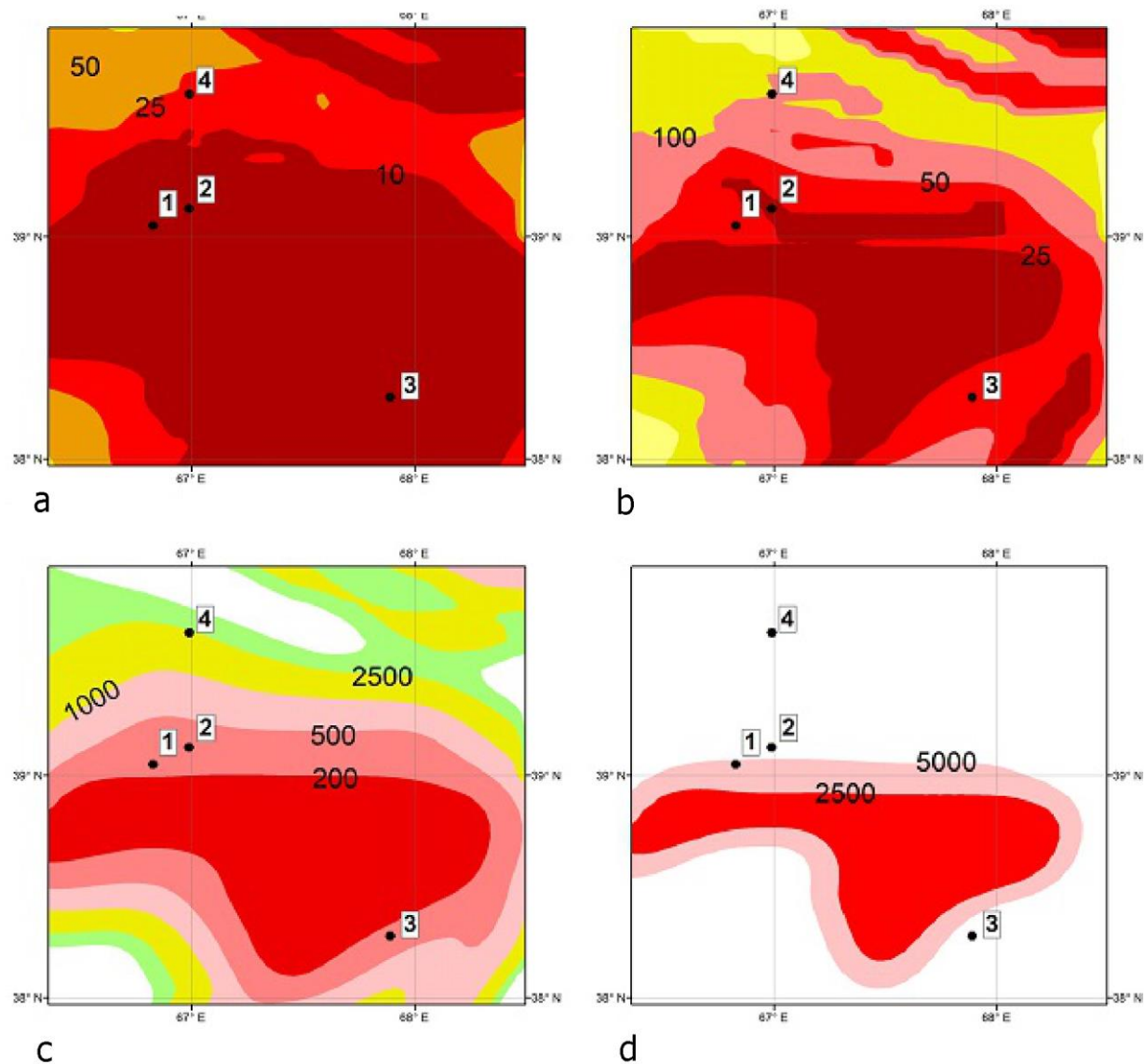
**Tab. 3** Periods of repetition of concussions with intensity  $I = 6-9$  points on scale MSK-64 for objects 1-4

Object	Periods of concussion repetition (T, years) with intensity $I = 6-9$ points on the scale MSK-64			
	$I = 6$	$I = 7$	$I = 8$	$I = 9$
1	10	30-40	300-400	5000
2	10	20-30	300-400	5000
3	10	0-40	300-400	>5000
4	25	100	1000-2000	>5000

location. Calculations were carried out taking into account the real soil conditions of each site on which the objects are located, for various probabilities not exceeding the level of seismic impacts for 50 years. Values of shear wave velocities of the upper soil layer VS30 for the site of each object were determined preliminary by seismic survey methods. Akkar and Bommer equation (Akkar and Bommer, 2010), was used as the predictive equation of ground movements (GMPE).

Tab. 4 shows numerical characteristics of values of maximum accelerations of soil oscillations for areas of objects location. Seismic acceleration spectra (PSA) for oscillation periods from 0.05 to 3 seconds at different probabilities of not exceeding the seismic impact level for 50 years are shown in Fig. 9.

Hazard curves of values of maximum accelerations of soil oscillations and spectral amplitudes for oscillation periods of 0.2 second and 1 second are given in Fig. 10 - 12. Values of maximum accelerations of soil oscillations (PGA) and their spectral amplitudes PSA (0.2 s) and PSA (1.0 s), respectively) are deposited along the abscissa axis. Along the ordinate axis is the annual probability of exceeding the level of seismic impact. Horizontal lines show the effects, with different repetition periods  $T = 75$  years,  $T = 475$  years,  $T = 975$  years,  $T = 2475$  years,  $T = 4975$  years and  $T = 10\ 000$  years.



**Fig. 8** *Periods of repetition of concussions with intensity:*  
a)  $I = 6$ ; b)  $I = 7$ ; c)  $I = 8$  d)  $I = 9$  points in the vicinity of objects

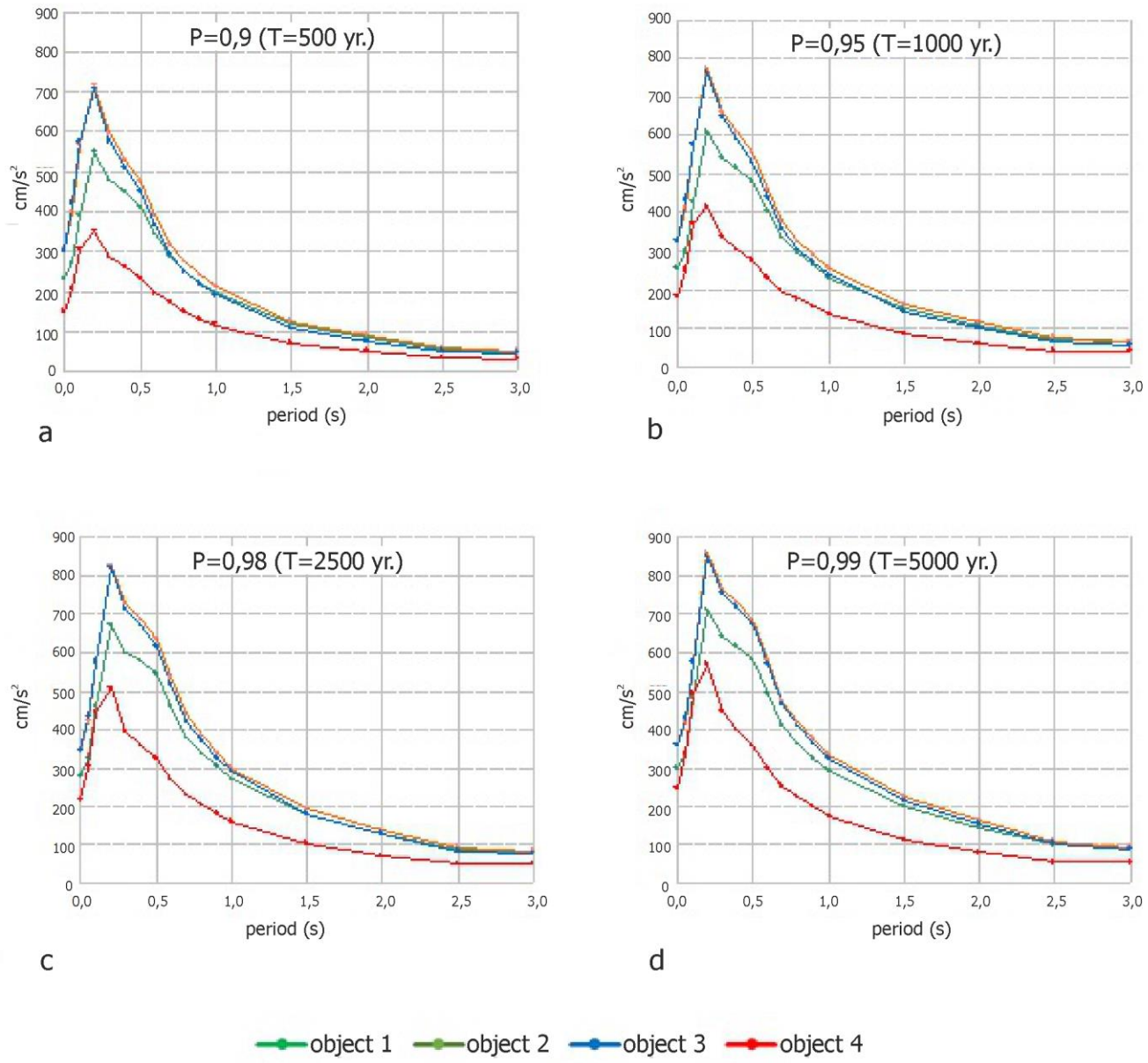
### 3. Historical monuments Seismic Stability Study

The method of measurement and processing was based on Nakamura method, on which seismometric studies were previously successfully carried out and carried out, including for assessing the vulnerability of architectural monuments (Colliseum, Pisa tower) and many administrative buildings and viaducts of expressways in Japan (Nakamura et al., 2000). Unlike other methods: methods of spectral relations of two stations (two site spectral ratio method - TSSRM) or spectral ratio method at one station (single site spectral ratio - SSSRM), better known as the horizontal component spectrum-to-vertical ratio method (the Horizontal to Vertical Spectrum Ratio - HVSRM) when registered under conditions of either absence or sharp weakening of man-made micro-oscillations, which require complex and often expensive organization of observations (Turnbull, 2008), in the method Nakamura, observations are performed by a single three-component seismological station for recording microseism of natural and anthropogenic (socially noisy) origin (Nakamura, 1989).

At the same time, no reference measurements are required at reference points, and the recording equipment itself moves along the observation points without synchronizing the records over time. This allows non-synchronous space and time measurements to be used in processing. It seems that the method Nakamura can be considered as one of the variants of the spectral ratio method (HVSRM). This method is based on the idea that the influence of the thin structure of the studied object mainly refers to transverse waves, which are amplified by this structure and practically do not change longitudinal waves. then the ratio of the spectral characteristics of the two horizontal components to the spectrum of the vertical component will characterize the so-called transfer function, which strictly depends on the thin structure of the studied object.

*Tab. 4 Maximum acceleration values (PGA, cm.s<sup>-2</sup>) for different probabilities not exceeding seismic impact level for 50 years at site locations 1–4*

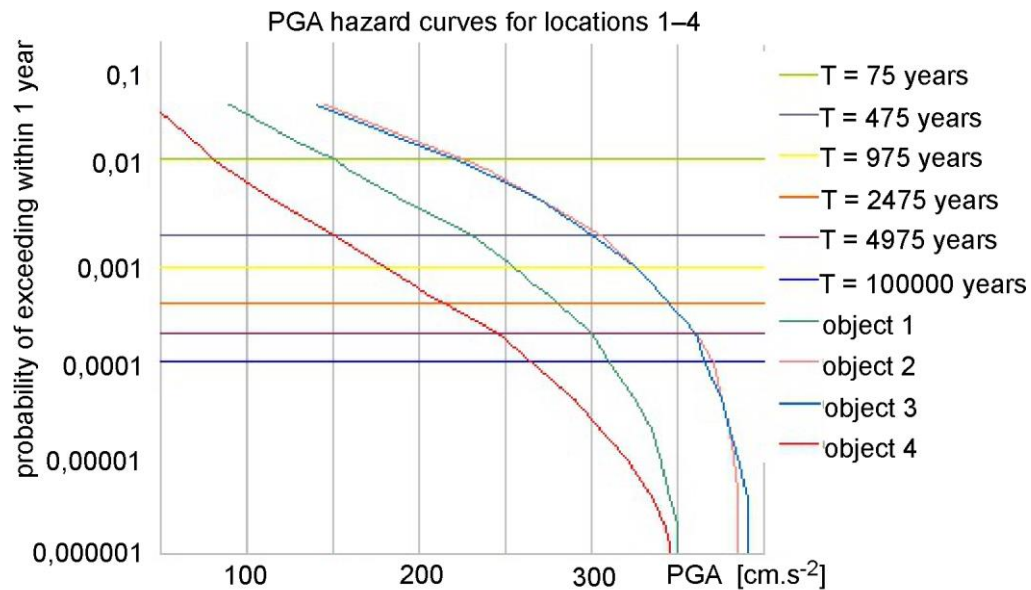
Object number	Peak acceleration values (PGA, cm.s <sup>-2</sup> ) for different probabilities not exceeding seismic impact level for 50 years			
	P = 0.9 (T = 500 years)	P = 0.95 (T = 1000 years)	P = 0.98 (T = 2500 years)	P = 0.99 (T = 5000 years)
1	230	255	280	300
2	305	325	345	360
3	300	325	345	360
4	150	180	215	245
<i>PGA (cm.s<sup>-2</sup>) - peak acceleration of soil oscillations on site</i>				



**Fig. 9 Spectral amplitudes of acceleration of soil oscillations at sites 1–4 of objects location, for different probabilities  $P$  not exceeding seismic impact level for 50 years: a)  $P = 0.9$ ; b)  $P = 0.95$ ; c)  $P = 0.98$ ; d)  $P = 0.99$**

This representation thus makes it possible to solve the problem of studying the fine structure of an object with respect to the spectra of the incident (input signal) oscillations, which are represented by the spectrum of the vertical component, and secondary-occurring (output signal), which are determined by the averaged spectrum of the horizontal components of the recorded oscillations in full accordance with the theory of solving black box problems. The applicability of Nakamura technique for a building as a wave propagation medium significantly different from soils is justified by using only its shear deformations. The building is considered as a system equivalent to virtual linear systems, in which records on horizontal channels are perceived as an output signal, and on vertical ones as an input signal. thus, in this case, the problem of the "black box" is solved - determining the characteristics of the body from the input and output signals.

The H/V spectrum ratio provides a spectral characteristic of the transfer function or a black box spectral characteristic. Nakamura method justifies in this approximation (Nakamura, 1989) the direct relationship of the private characteristic of the transfer function with the amplitudes of possible shear deformations in the building. It follows that resonances



**Fig. 10 PGA hazard curves for locations 1–4**

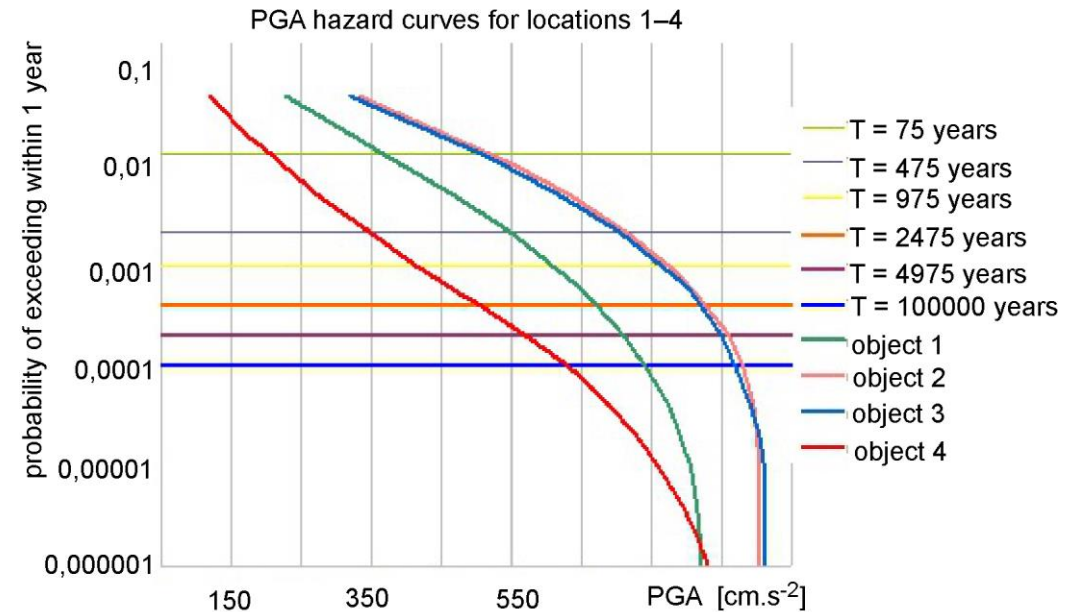
(peaks) of a particular characteristic indicate the presence of resonances at shear deformations at given frequencies and their increased ability to damage at these frequencies under the influence of applied external loads.

The formula for determining the maximum shift by (Nakamura, 2000) is:

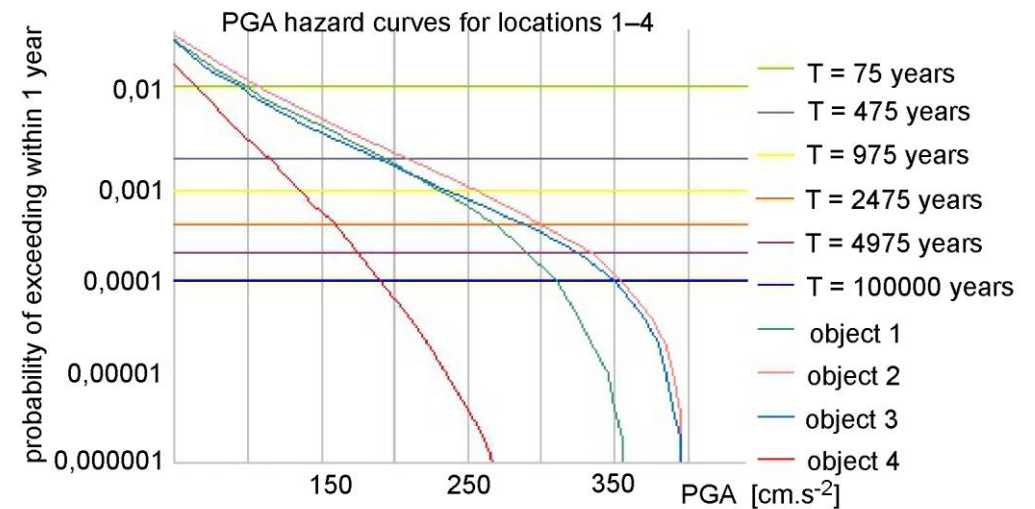
$$A_{\max} = 104(4\pi^2 F^2 h_j/A_1 - A_o)Y$$

- where  $A$  maximum horizontal acceleration;
- $F$  is the prevailing frequency at a given measurement point;
- $h_j$  - height of  $j$  floor;
- $A_1$  - reinforcement factor of  $j$  floor;
- $Y$  - angle of possible deformation level  $j$  of floor.

Microseismic measurements were made using the TROMINO instrument (Italy). First of all, the HVSr spectrum for the soils under the structure was determined.



**Fig. 11 Hazard curves PSA (0.2) for locations 1–4**



**Fig. 12 Hazard curves PSA (1.0) for locations 1–4**

### 3.1 Said Otalik Madrasah (Denau)

Said Otalik Madrasah is a two-storey madrasah built in the 16th century, during the reign of the Shaibanids, under the leadership of Ahmad Mamat Bukhari, an architect from Bukhara. The largest madrasahs of Bukhara were built in the style of Kukaldosh and other madrasahs. Currently, this type of madrasah is the only one in the Surkhandarya region. The madrasah is now in disrepair, and on the verge of destruction. In 2021, the building of the madrasah was in disrepair and was on the verge of collapse. The madrasah is included in the national list of “Intangible Cultural Heritage Real Estate” approved in 2019, in which it is planned to build a crafts center.

Measurements were taken at 6 registration points - on the ground, on the roof of the building (Akkar and Bommer, 2010) and on one of the minarets. Below are HVSR spectra for all registration points (Fig. 14). From the obtained HVSR spectra, the main parameters characterizing the structure (natural oscillation frequency, oscillation gain, seismic instability coefficient and maximum accelerations that the building will withstand without losing structural connections are obtained (Tab. 5).

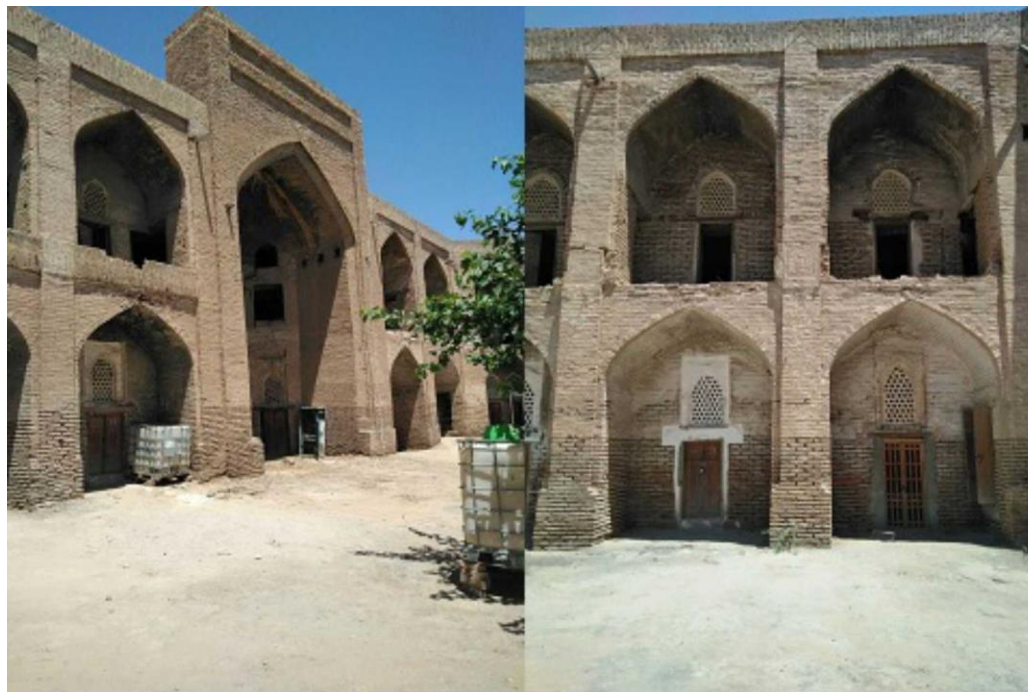


Fig. 13 Madrasah Said Otalik

Tab. 5 Maximum acceleration values (PGA,  $cm.s^{-2}$ ) for different probabilities not exceeding seismic impact level for 50 years at site locations 1-4

	Point 1		Point 2		Point 3		Point 4		Point 5	
	$F_0$	HVSR	$F_0$	HVSR	$F_0$	HVSR	$F_0$	HVSR	$F_0$	HVSR
$A_{max} [cm.s^{-2}]$	5.91	3.14	6.20	4.37	6.38	2.92	5.72	3.39	4.80	3.08
<b>I (degree)</b>	6		6		6.5		6		6	
<p>Here: <math>F_0</math>- natural frequency of oscillations of the building, <math>A_{max}</math> – maximum acceleration that will withstand the building, <math>I</math> - maximum intensity of seismic impacts, safe for the building.</p>										

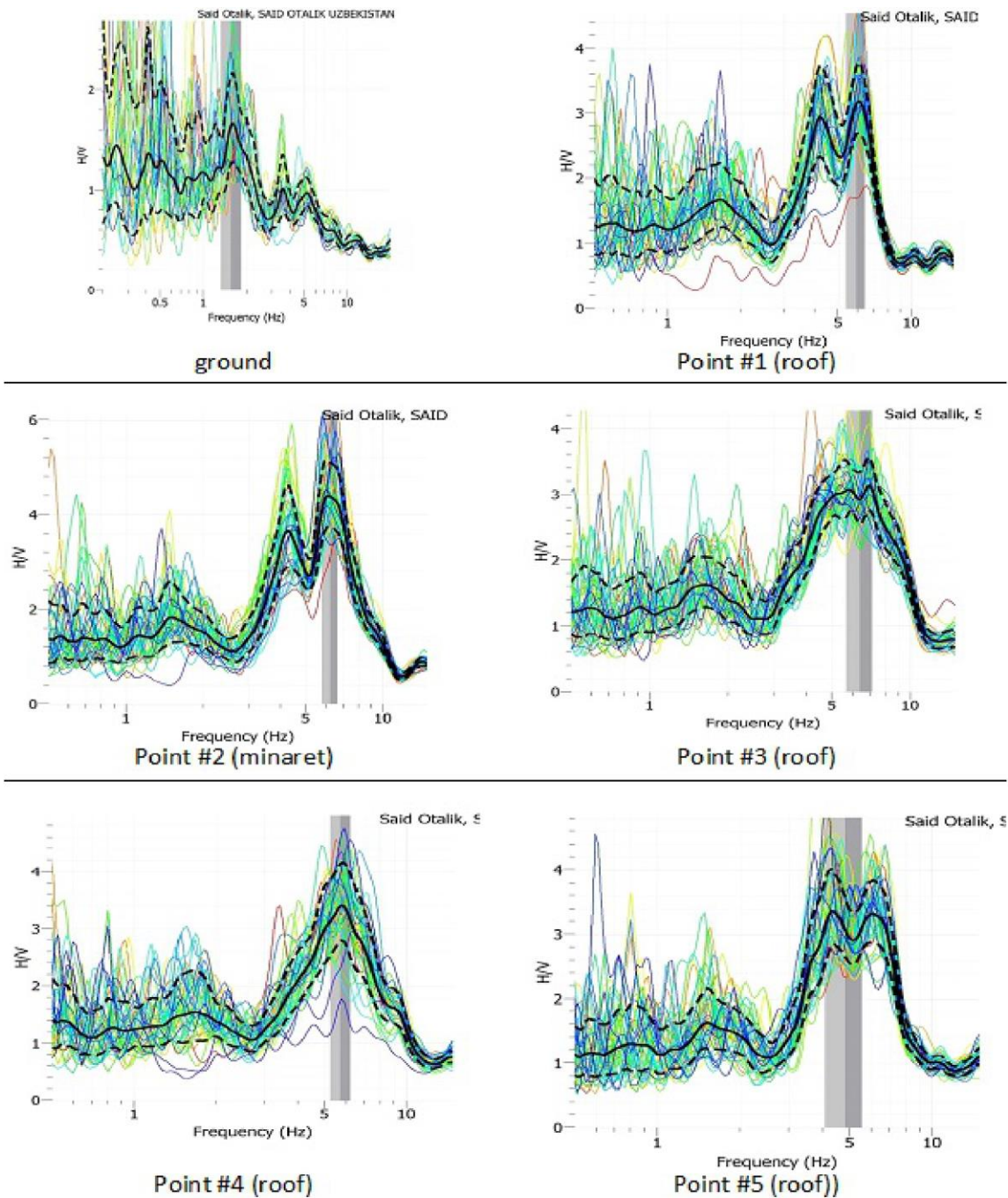


Fig. 14 HVSR spectra for all registration points

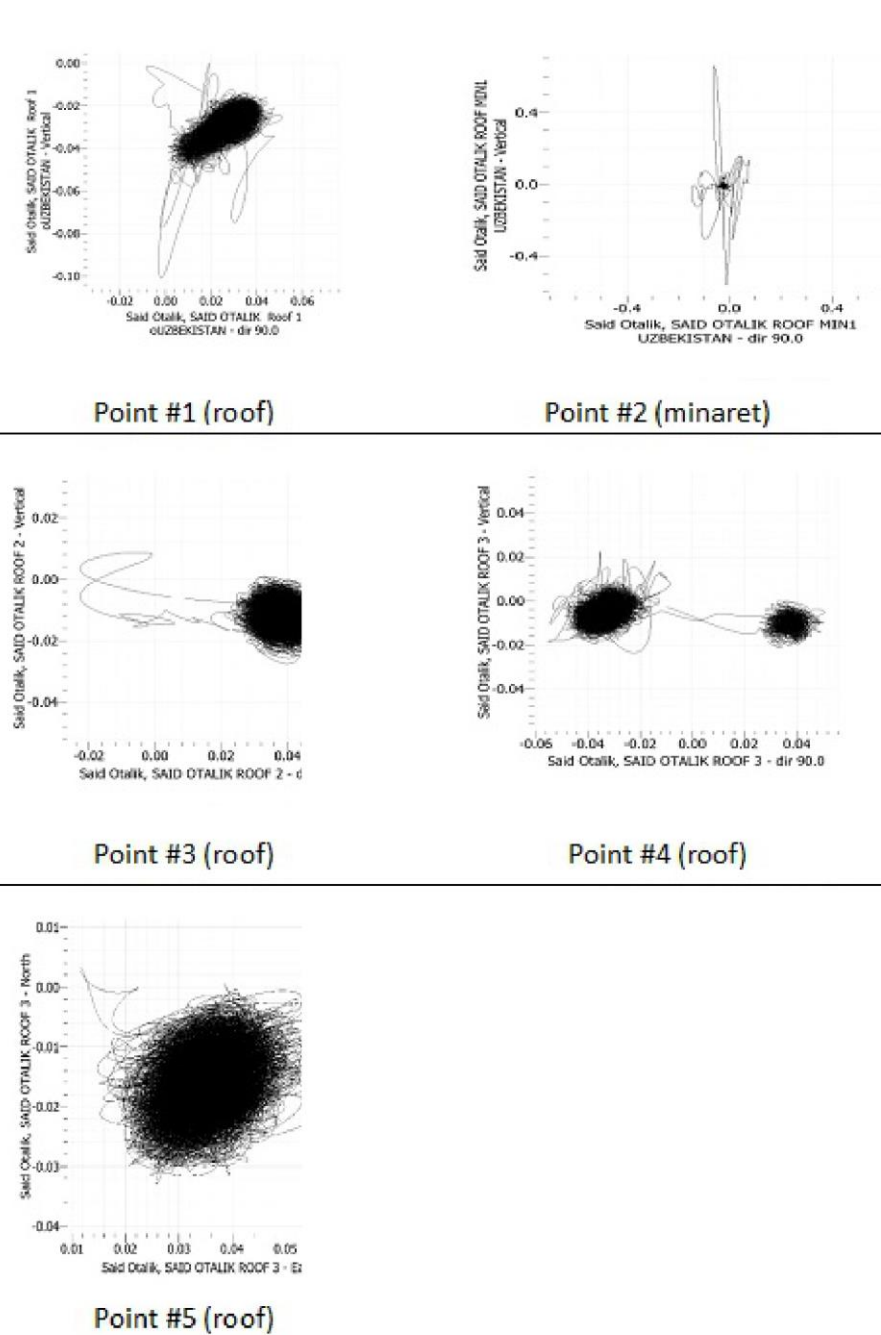


Fig. 15 Movement (eigenwear) vectors for measured points

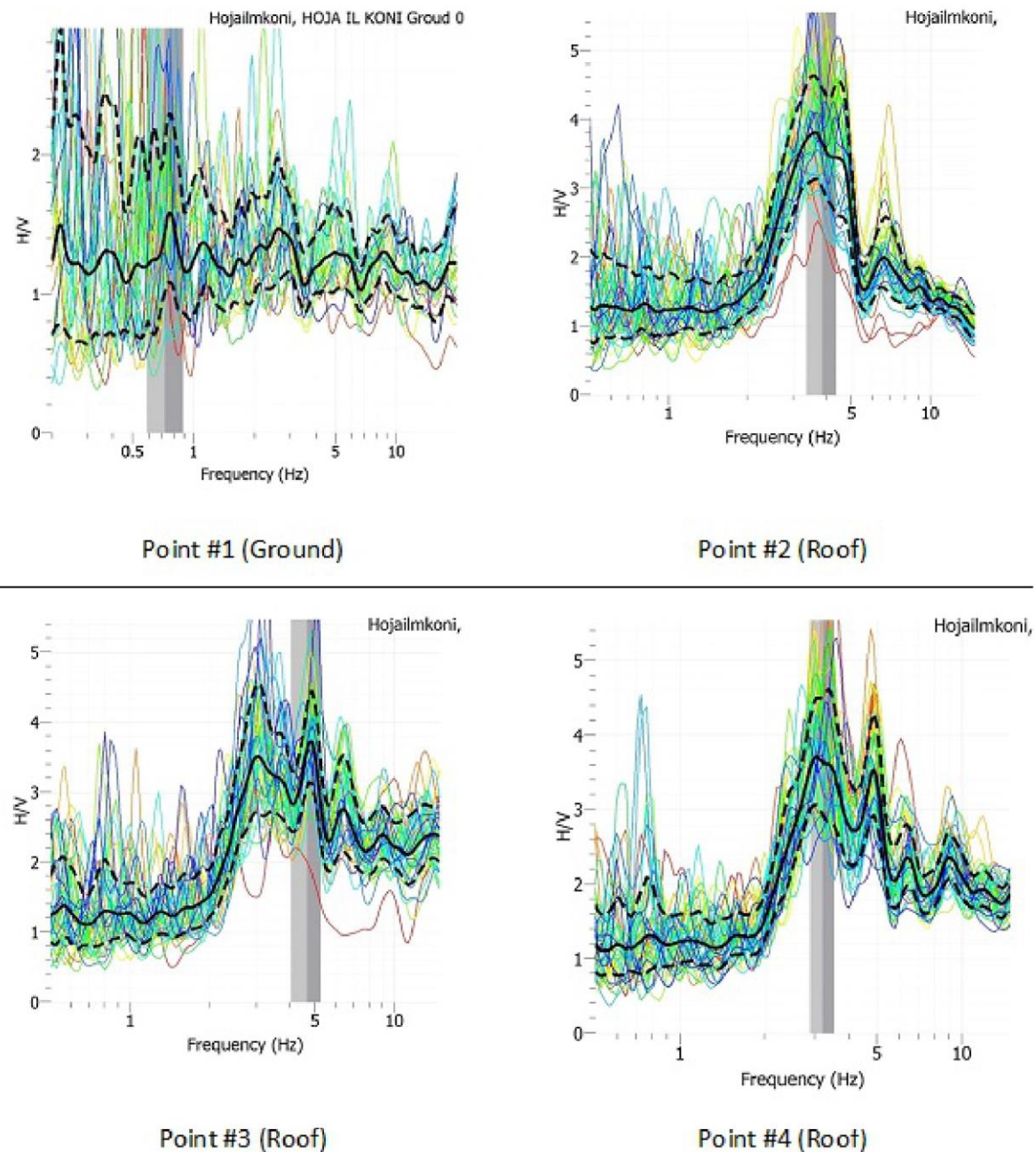
Useful information about the rigidity of the structure can be obtained from the vector of natural vibrations of the structure. The following are motion vectors at registration points (Fig.15).

Here, at registration points 1, 5, there is a trend of fluctuations from southwest to northeast, point No. 4 - east-west, the minaret fluctuates from north to south with a large amplitude.

Comparing the expected seismic impacts over a period of 50 years for a probability of 90 % -  $300 \text{ cm.s}^{-2}$  with the obtained acceleration values ( $42.3\text{--}90.7 \text{ cm.s}^{-2}$ ), it can be concluded that the madrasah needs to increase the strength of the structure.



**Fig. 16 Khuzha Ilm Koni Mausoleum**



**Fig. 17 HVSr spectra for measurement points**

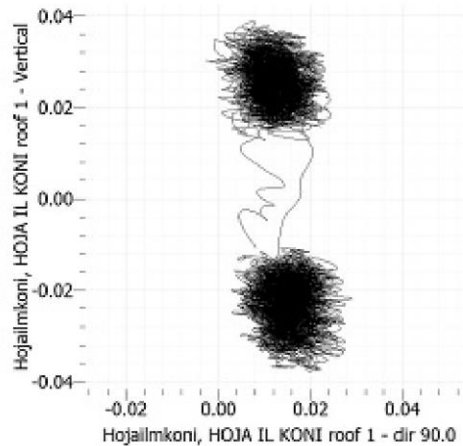
### 3.2 Khuzha Ilm Koni Mausoleum (Kitab)

The mausoleum of Khuzha Ilm Koni was built in the 17th century. Here, microseism measurements were carried out at 4 points, 1 - soil, 3 - on the roof, since the roof of the structure is covered with iron with zinc, it was not possible to install the device on stone material everywhere (Fig. 17).

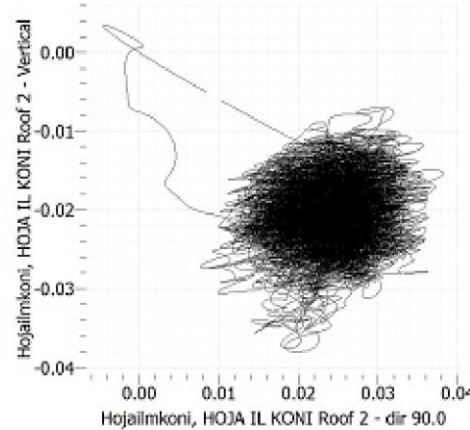
Comparison of the expected seismic impacts for 50 years for 90 % probability -  $305 \text{ cm.s}^{-2}$ , with the obtained acceleration values ( $12.8\text{--}19.5 \text{ cm.s}^{-2}$ ), shows that the mausoleum needs to increase the strength of the structure.

**Tab. 6 Calculation results for Khuzha Ilm Koni Mausoleum**

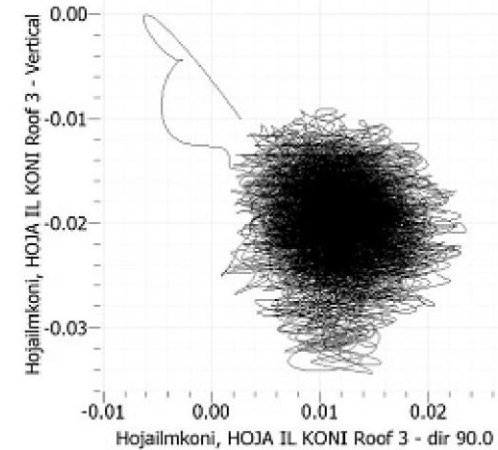
	Point 1		Point 2		Point 3	
	F <sub>o</sub>	HVSR	F <sub>o</sub>	HVSR	F <sub>o</sub>	HVSR
<b>A<sub>max</sub> [cm.s<sup>-2</sup>]</b>	3.858	3.866	3.151	3.49	3.200	3.638
<b>I (degree)</b>	5		4.5		4.5	



Point #1



Point #2



Point #3

**Fig. 18 Movement (eigenwear) vectors for measured points**

Here for point # 1 there is a hopping of the displacement vector.

### 3.3. Kuk Gumboz Mosque, Shahrissabz

In 1435, 30 years after the death of Amir Timur, the largest mosque in Shahrissabz was opened - Kuk Gumboz. The rich architectural structure was sustained in the style of the 15th century by talented masters close to the ruler of that time, Mirzo Ulugbek. The mosque crowns a magnificent huge dome covered with blue ceramic tiles. Hence the name of the mosque - Kuk Gumboz, which means "Blue Dome."

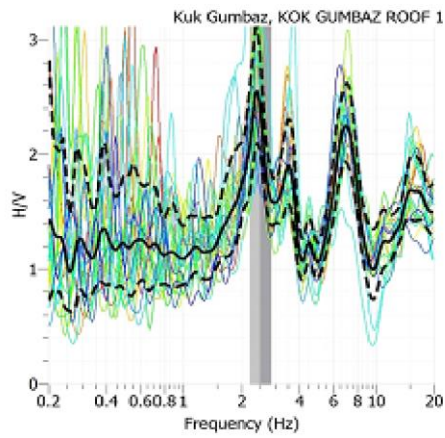
Microseism measurements were made at 5 registration points - 1 soil, 4 on the roof of the building (Fig. 20).



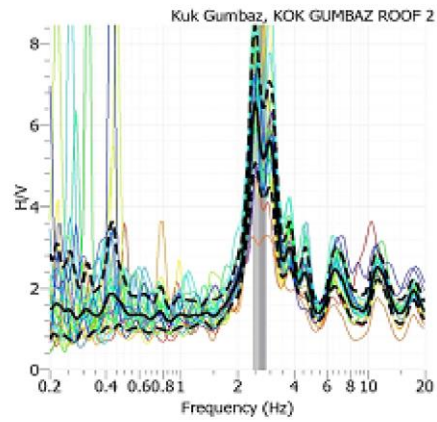
*Fig. 19 Kuk Gumboz Mosque*

*Tab. 7 Design parameters for Kuk Gumboz Mosque*

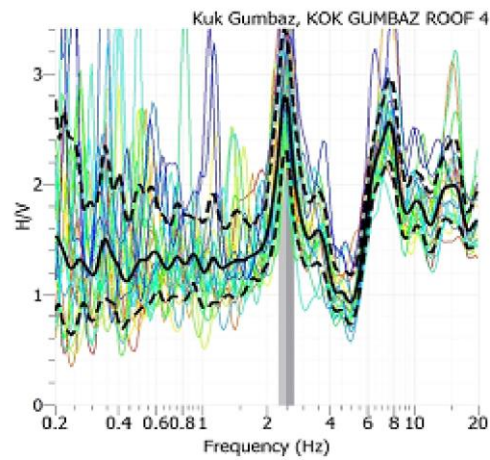
	Point 1		Point 2		Point 3		Point 4	
	F <sub>0</sub>	HVSR	F <sub>0</sub>	HVSR	F <sub>0</sub>	HVSR	F <sub>0</sub>	HVSR
<b>A<sub>max</sub> [cm.s<sup>-2</sup>]</b>	2.513	2.380	2.652	5.813	2.485	2.778	2.509	11.204
<b>I (degree)</b>	7.5		7.5		7		7.5	



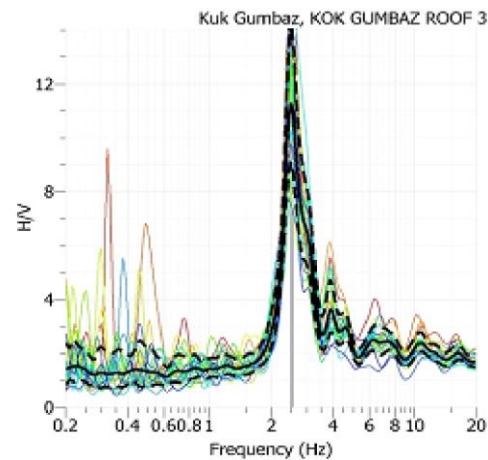
Point #1



Point #2



Point #3

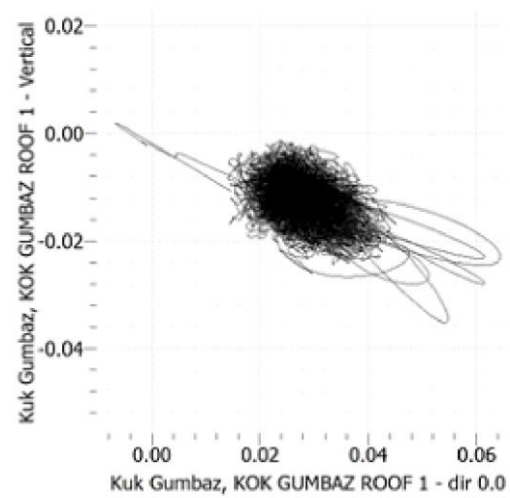


Point #4

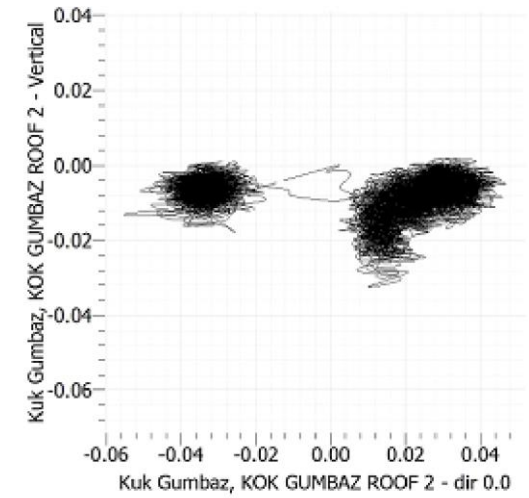
**Fig. 20 HVSR spectra for measured points**

Eigenwear vector:

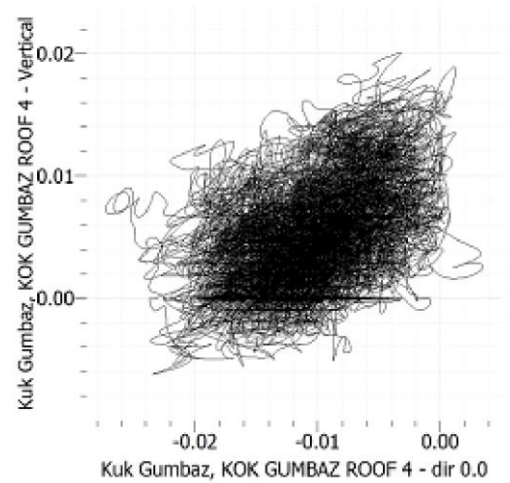
Registration points 1, 3, 4 show the direction of their own fluctuations from the south-west to the north-east, point No. 2 - east-west



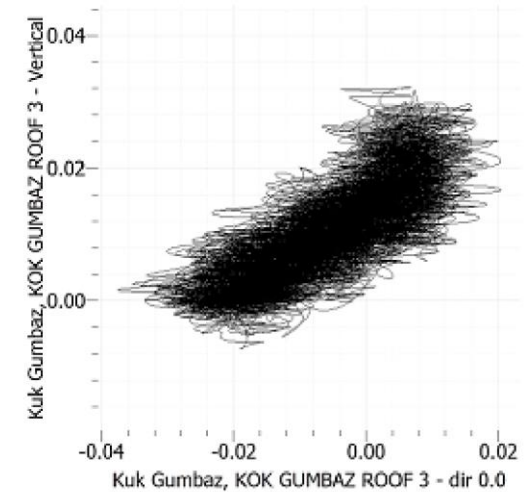
Point #1



Point #2



Point #3



Point #4

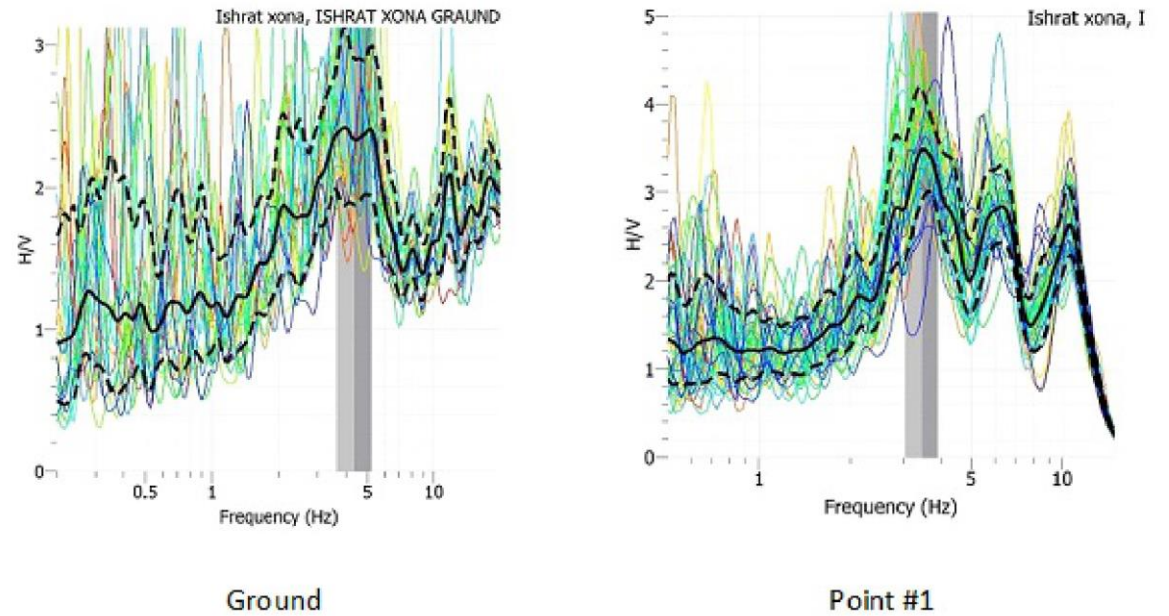
**Fig. 21 Movement (eigenwear) vectors for measured points**

The design has high rigidity, natural frequencies differ slightly (2.485–2.652 Hz). Maximum seismic loads that the building will withstand without loss of structural connections (the beginning of destruction) are high 127–228  $\text{cm.s}^{-2}$ , which corresponds to intensities on a scale of EMS-98 7–7.5 points. The eigenwear vector for point No. 4 also shows a pronounced direction from southwest to northeast. Differences in the characteristics of point No. 4 give rise to the conclusion about the features of the building, a crack may have arisen in one of the walls, which weakens structural connections. The maximum expected acceleration for 50 years for 90 % probability is 230  $\text{cm.s}^{-2}$ , so the building structure can be considered relatively stable.

### 3.4 Ishratkhona Mausoleum, Samarkand

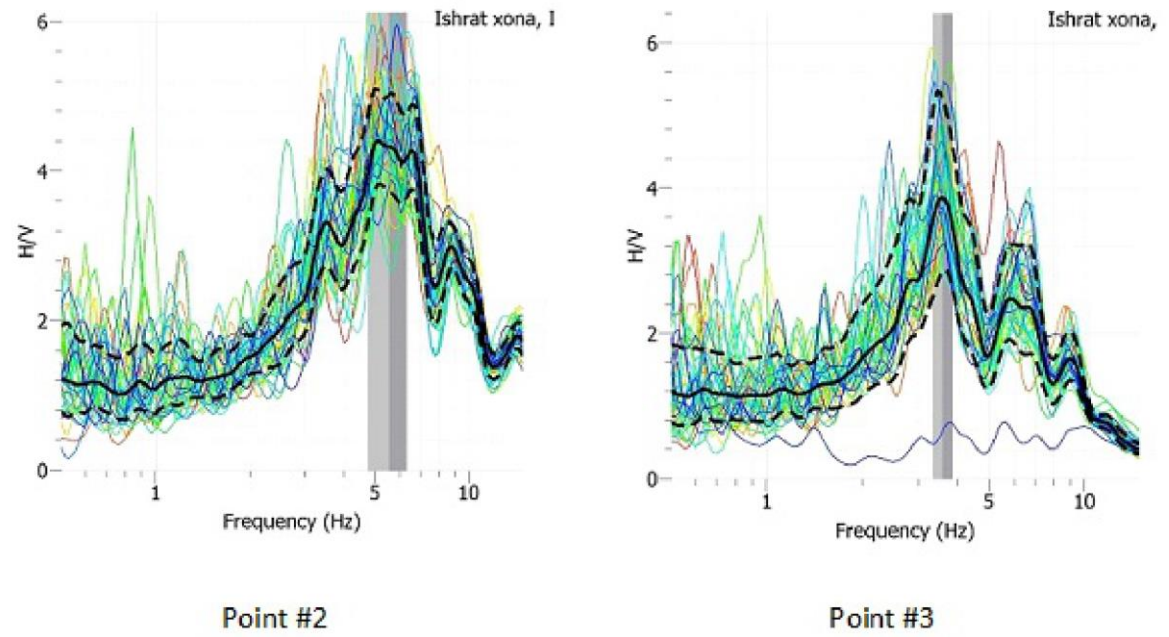


*Fig. 22 Ishratkhona Mausoleum*



Ground

Point #1



Point #2

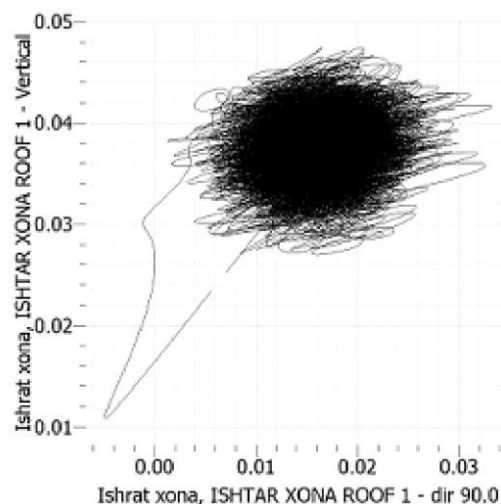
Point #3

*Fig. 23 HVSR for measured points*

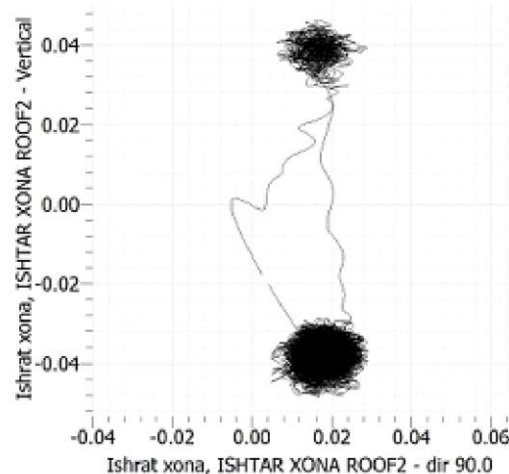
The Ishratkhona Mausoleum in Samarkand is part of the world heritage (Fig. 22). It belongs to the most significant structures in Central Asia and today is of invaluable importance, not because it is in a damaged state, but because it was because of this state that it was little susceptible to modification and distortion.

**Tab. 8 Design parameters for Ishratkhona Mausoleum**

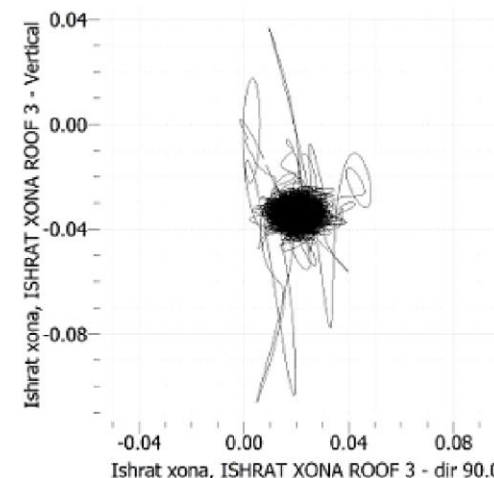
	Point 1		Point 2		Point 3	
	F <sub>0</sub>	HVSR	F <sub>0</sub>	HVSR	F <sub>0</sub>	HVSR
A <sub>max</sub> [cm.s <sup>-2</sup> ]	3.450	3.485	5.533	4.330	3.573	3.861
I (degree)	6.5		6		5.5	



Point #1



Point #2



Point #3

**Fig. 24 Movement (eigenwear) vectors for measured points**

Here, for points 2, 3, there are intrinsic fluctuations in the south-west direction with a sufficiently large amplitude. The maximum accelerations withstood by the building without losing structural bonds are 27.6 cm.s<sup>-2</sup>, which corresponds to 5.5 points on the MSK-64 scale. For this object, the maximum expected accelerations for 50 years for a probability of 90 % are 150 cm.s<sup>-2</sup>, which is five times higher than the accelerations withstood by the structure.

## 4. Conclusion

- **Said Otalik Madrasah** - Comparing the expected seismic impacts within 50 years for a probability of 90 % – 300 cm.s<sup>-2</sup> with the obtained acceleration values (42.3–90.7 cm.s<sup>-2</sup>), it can be concluded that the madrasah needs to increase the strength of the structure.
- **Khuzha Ilm Koni Mausoleum** - Comparison of the expected seismic impacts over 50 years for a probability of 90 % – 305 cm.s<sup>-2</sup>, with the obtained acceleration values (12.8–19.5 cm.s<sup>-2</sup>), shows that the mausoleum needs to increase the strength of the structure.
- **Kuk Gumboz Mosque** - The weakest section of the mosque will withstand an acceleration of 127 cm.s<sup>-2</sup>. The maximum expected acceleration over 50 years for 90 % probability is 230 cm.s<sup>-2</sup>, so the building design can be considered relatively stable.
- **Ishratkhona Mausoleum** - The maximum accelerations sustained by the building without losing structural links are 27.6 cm.s<sup>-2</sup>, which corresponds to 5.5 points on the MSK-64 scale. For this object, the maximum expected accelerations over 50 years for 90 % probability are 150 cm.s<sup>-2</sup>, which is five times the accelerations sustained by the structure.

Studies of seismic stability of four cultural heritage sites in Uzbekistan have shown that three out of four have a large deficit of seismic resistance and work is required to strengthen them.

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