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ASSESSMENT OF THE SOIL SEISMIC CONDITION THROUGH MICROSEISMIC MEASUREMENTS (IN THE EXAMPLE OF THE CITY OF BUKHARA)

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Abstract. This article presents a study on microseismic analysis and the assessment of seismic properties in Bukhara. The research aims to determine the city's geological structure and seismic wave propagation velocities across different layers using microseismic methods. These methods provide essential data for seismic hazard assessment and construction planning. The study analyzed H/V ratios, microseismic spectra, and the dynamic properties of various soil layers by measuring seismic wave velocities. Specialized instruments, such as the “Guralp” seismometer, were used to record and analyze microseismic noise. To evaluate and classify the seismic condition of Bukhara’s soil, the average shear wave velocity at a depth of 30 meters (Vs30) was calculated. The reliability of the method was confirmed through seismic surveys (MASW) conducted in the area. The Nakamura method was employed to analyze seismograms, yielding effective results in detecting seismic waves despite urban noise and challenging survey conditions. Microseismic measurements were conducted at 44 points, with 20-minute oscillations recorded at each location. The processed data led to the creation of a Vs30 map of Bukhara, a crucial tool for seismic hazard assessment and safe construction planning. Ultimately, these microseismic studies provide valuable insights into Bukhara's seismic characteristics, contributing to risk reduction and the development of safer, more sustainable construction practices.

Key words: seismic, microseismic, seismogram, grunt, vibration, earthquake, speed, wave

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МИКРОСЕЙСМИКАЛЫҚ ӨЛШЕМДЕР АРҚЫЛЫ ТОПЫРАҚ СЕЙСМИКАЛЫҚ ЖАҒДАЙЫН БАҒАЛАУ (БҰХАРА ҚАЛАСЫНЫҢ МЫСАЛЫНДА)

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Аннотация. Бұл мақалада Бұхарадағы микросейсмикалық талдау және сейсмикалық қасиеттерді бағалау бойынша зерттеу берілген. Зерттеу микросейсмикалық әдістерді қолдана отырып, қаланың геологиялық құрылымын және әртүрлі қабаттар бойынша сейсмикалық толқындардың таралу жылдамдығын анықтауға бағытталған. Бұл әдістер сейсмикалық қауіпті бағалау және құрылысты жоспарлау үшін маңызды деректер береді. Зерттеу барысында сейсмикалық толқындардың жылдамдығын өлшеу арқылы H/V қатынасы, микросейсмикалық спектрлер және әртүрлі топырақ қабаттарының динамикалық қасиеттері талданды. Микросейсмикалық шуды тіркеу және талдау үшін «Гуральп» сейсмометрі сияқты арнайы құралдар пайдаланылды. Бұхара топырағының сейсмикалық жағдайын бағалау және жіктеу үшін 30 метр тереңдіктегі ығысу толқындарының орташа жылдамдығы (Vs30) есептелді. Әдістің сенімділігі ауданда жүргізілген сейсмикалық барлаулар (МАСЖ) арқылы расталды. Накамура әдісі сейсмограммаларды талдау үшін қолданылды, қалалық шу мен күрделі зерттеу жағдайларына қарамастан сейсмикалық толқындарды анықтауда тиімді нәтижелер берді. Микросейсмикалық өлшеулер 44 нүктеде жүргізілді, әр жерде 20 минуттық тербелістер тіркелді. Өңделген деректер сейсмикалық қауіпті бағалау және құрылысты қауіпсіз жоспарлаудың маңызды құралы болып табылатын Бұхараның Vs30 картасын жасауға әкелді. Сайып келгенде, бұл микросейсмикалық зерттеулер Бұхараның сейсмикалық сипаттамалары туралы құнды түсініктер береді, тәуекелді азайтуға және қауіпсіз, тұрақты құрылыс тәжірибесін дамытуға ықпал етеді.

Түйін сөздер: сейсмика, микросейсмика, сейсмограмма, топырақ, діріл, жер сілкінісі, жылдамдық, толқын

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ОЦЕНКА СЕЙСМИЧЕСКОГО СОСТОЯНИЯ ГРУНТОВ ПУТЕМ МИКРОСЕЙСМИЧЕСКИХ ИЗМЕРЕНИЙ (НА ПРИМЕРЕ ГОРОДА БУХАРЫ)

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Аннотация. В статье представлена информация о микросейсмических исследованиях и оценке сейсмических свойств грунтов города Бухары. Эти исследования направлены на определение геологической структуры территории и характеристик сейсмических волн в различных слоях грунта с использованием микросейсмических методов. Применённый метод позволяет получить данные о сейсмической опасности в городской среде, необходимые для проектирования и строительства. В ходе работы были изучены динамические свойства различных слоёв грунтов на основе соотношений H/V, микросейсмических спектров и скоростей распространения сейсмических волн. Представлены анализ микросейсмических помех, описание применяемого оборудования (в частности, сейсмометра “Guralp”) и подробные сведения о результатах измерений, необходимых для определения и оценки сейсмического состояния грунтов городской территории. В Бухаре рассчитаны средние значения скорости поперечной волны, распространяющейся на глубине до 30 метров (Vs30), для оценки сейсмического состояния и классификации грунтов. Надёжность метода подтверждается результатами полевых сейсморазведочных исследований (MASW). Предложенный подход показал эффективность при решении проблем, возникающих при проведении геолого-геофизических работ в условиях городских сейсмических помех и сложных инженерно-геологических условий. При анализе сейсмограмм использовался метод Накамуры, обеспечивший получение достоверных результатов при регистрации сейсмических волн. Микросейсмические измерения были выполнены в 44 точках, при этом в каждой точке регистрировались 20-минутные колебания. На основе обработанных данных составлена карта Vs30 города Бухары, которая играет важную роль в оценке сейсмической опасности территории и предоставляет необходимую информацию для обеспечения безопасности и устойчивости строительных объектов. Проведённые исследования способствуют углублённому изучению сейсмических особенностей городской территории, снижению потенциальной сейсмической опасности и повышению надёжности проектных решений.

Ключевые слова: сейсмика, микросейсмика, сейсмограмма, грунт, вибрация, землетрясение, скорость, волна

Introduction. The microseismic measurement method is used to study the soil of Bukhara city. It is known that in urban areas, due to the dense location of buildings, the continuous movement of vehicles and several other factors, it is difficult to determine the velosity of waves propagation in soil. Since a small area is enough for measurements, the microseismic method provides convenience for working in the city. It is known that the geological formation of the area is an important factor, and the damage caused by earthquakes is greatly influenced by the local site conditions (Seed and Idriss, 1969). In addition, it depends on the dynamic properties of the soil and the depth of the sediment layer during an earthquake and the speed of its seismic wave transmission. Increased seismicity in sedimentary layers can be estimated using the microtremor measurement technique introduced by Kanai et al., 1954. Number of studies showed that the results of microtremor analysis are reliable (Field et al., 1993; Fieldand, 1990, Jacob, 1993). According to them, the source effect can be removed by dividing the horizontal component of the microtremor spectrum into the vertical component. This technique is an inexpensive and efficient method to estimate the fundamental resonance frequency of widespread sediments using the Horizontal to Vertical (H/V) spectral ratio determined from a single station. In his paper, (Nakamura, 1989) explains the use of this technique and provides a detailed explanation of the future assumptions.

In the last two decades, the H/V method has become widely used. Soil impact assessment, wave amplification assessment, liquefaction vulnerability assessment, depth estimation for various purposes such as sedimentation and microzonation studies in different geographic and geological regions of the world, a lot of works (Field and Jacob, 1993 a; Bour et al., 1998; Ibs- von Secht and Wollenberg, 1999; Delgado et al., 2000; Hasancebi and Ulusoy, 2006) have been done by scientists.

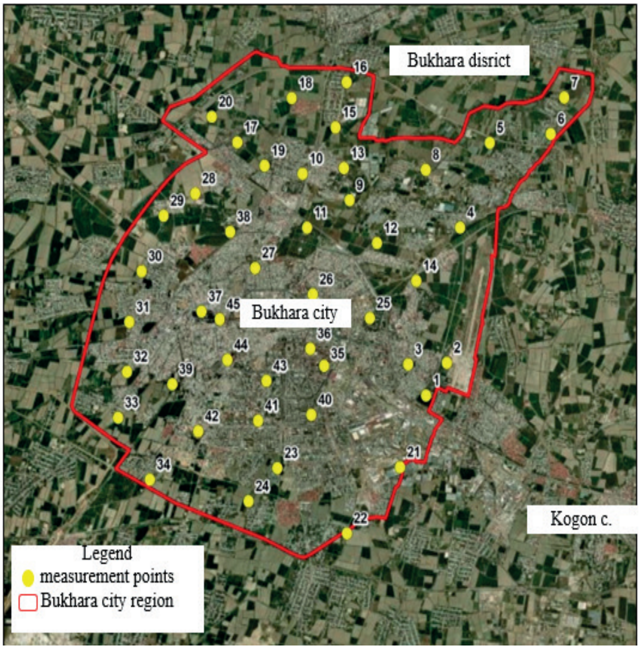


Figure 1. Schematic map for the location of instrumental research points of Bukhara city

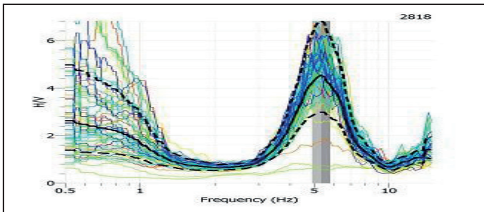
Research materials and methods. "Guralp" seismometer was used to measure microseismic waves in ground vibrations of the city. This seismometer is a digital three-component seismometer that simultaneously records azimuthal and vertical components of ground dynamics (Ibragimov A.Kh et al., 2016).

In order to analyze the soil condition in the city, measurement work was carried out at a total of 44 points. During seismometric field recording, the seismometer is directed to the north and brought to a horizontal position. Each measurement is required to last 30 minutes. Using a seismometer, 3 components (x, y, z) of seismic vibrations are recorded.

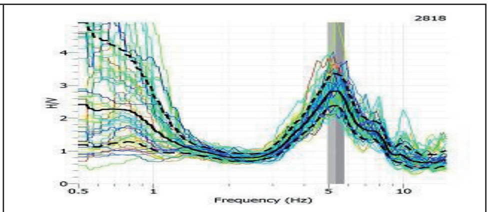
The obtained seismograms demonstrate the vibration of the ground. For the interpretation of the seismograms, the Nakamura method is used. The explanation of the nature of the wave by the H/V ratio, which is accepted as a basis by most researchers, is expressed as follows:

- microseismic noise mainly consists of surface waves (therefore, the vertical component corresponds mainly to the Rayleigh wave);
- The ellipse H/V ratio of the Rayleigh waves varies with the frequency (f) corresponding to a certain depth of research.

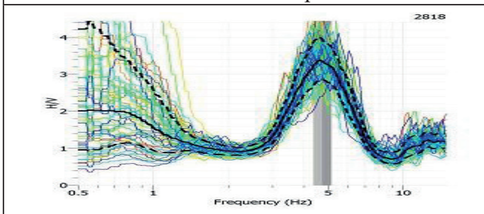
The Nakamura method is based on the spectrum of H/V ratios of the horizontal and vertical components of microseismic vibrations, which represent the analogue of the amplitude-frequency characteristic for the entire thickness of the geological formation (García-Jerez A et al., 2016; Bignardi S et al., 2016).



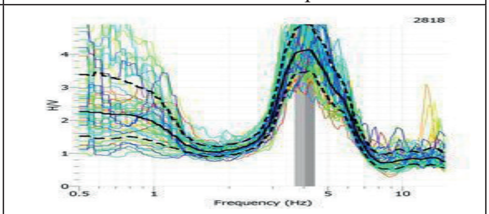
1 – measurement point



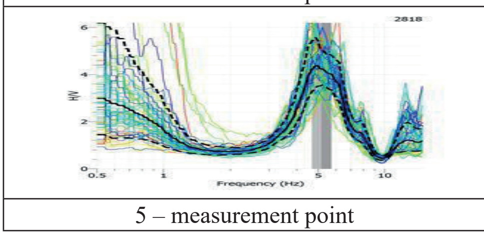
2 – measurement point



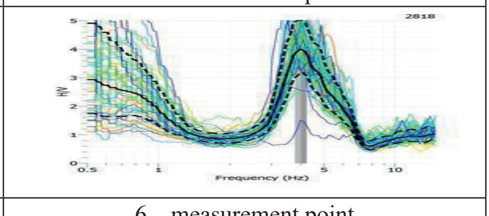
3 – measurement point



4 – measurement point



5 – measurement point



6 – measurement point

Figure 2. HVSR spectrum of some measurement points taken in the area

Instrumental studies carried out in Bukhara city are very necessary to evaluate the strength and seismic resistance of the soil. During the study of the foundations of the buildings and structures under construction, the compression and shear wave velocities which are calculated as seismic parameters of the layers lying to a certain depth, are determined using HVSR spectra. Shear wave velocity (Vs30) is mainly used in the analysis of loose (water-absorbing) soils. Because shear waves velocity is considerably small in a saturated soils. Therefore, it is necessary to determine the velocity of shear waves mainly up to the lifting part in soils (30-50 m). During the assessment of ground seismic conditions (Vs30) through microseismic measurements, following data are obtained for the city of Bukhara.

When processing microseismic measurement data using the "Dinver" program, ground seismic parameters are employed (Fig. 2).

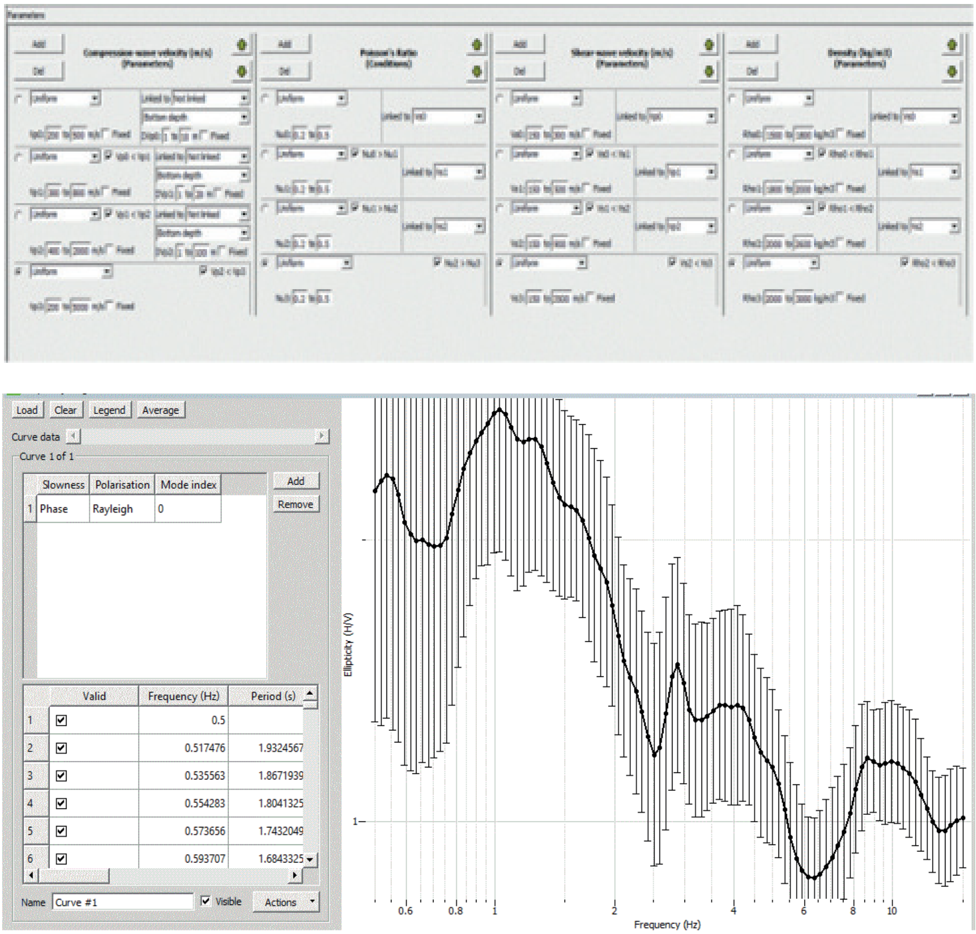


Figure 3. Seismic parameters window
(Graph of dependence of seismic parameters and H/V amplitude ratio on ground natural vibration frequency)

During seismogram processing, various disturbing waves (seismic noise) are removed. This helps to separate the characteristic vibration's wave parameters (f0, A0). Here: H/V is the ratio of the horizontal and vertical soil vibrations, f0 is ground resonance frequency (Aaqib et al., 2021).

Velocity and density values are obtained with the help of graphs representing the characteristic oscillation of the soil (Fig. 5). Changes in seismic wave velocities (VS, VP) and density of the medium with depth may indicate that the soil is not homogeneous. However, considering that the composition of the soil consists of sedimentary deposits, this does not mean that the density and acoustic stiffness of the soil have the same value. As a result, (VS, VP) also changes with increasing depth (Aaqib et al., 2022; Ismailov et al., 2023).

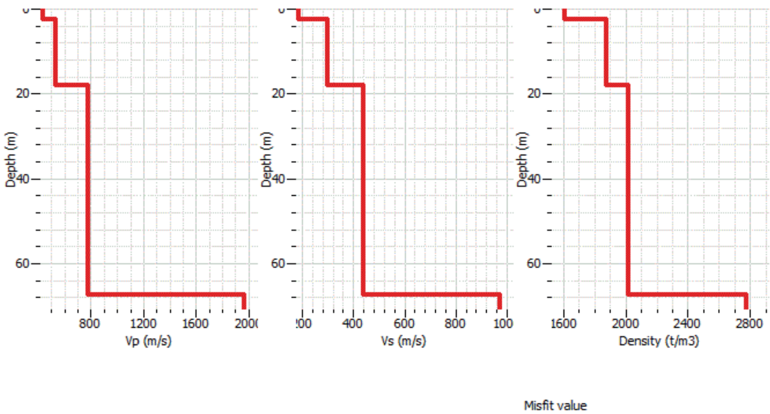
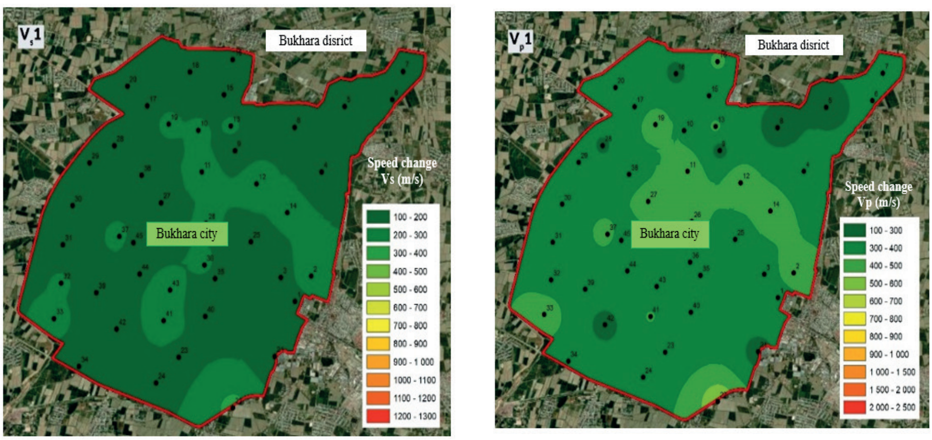


Figure 4. Graph of depth variation of shear and pressure wave velocities as well as bulk density for one measurement point.



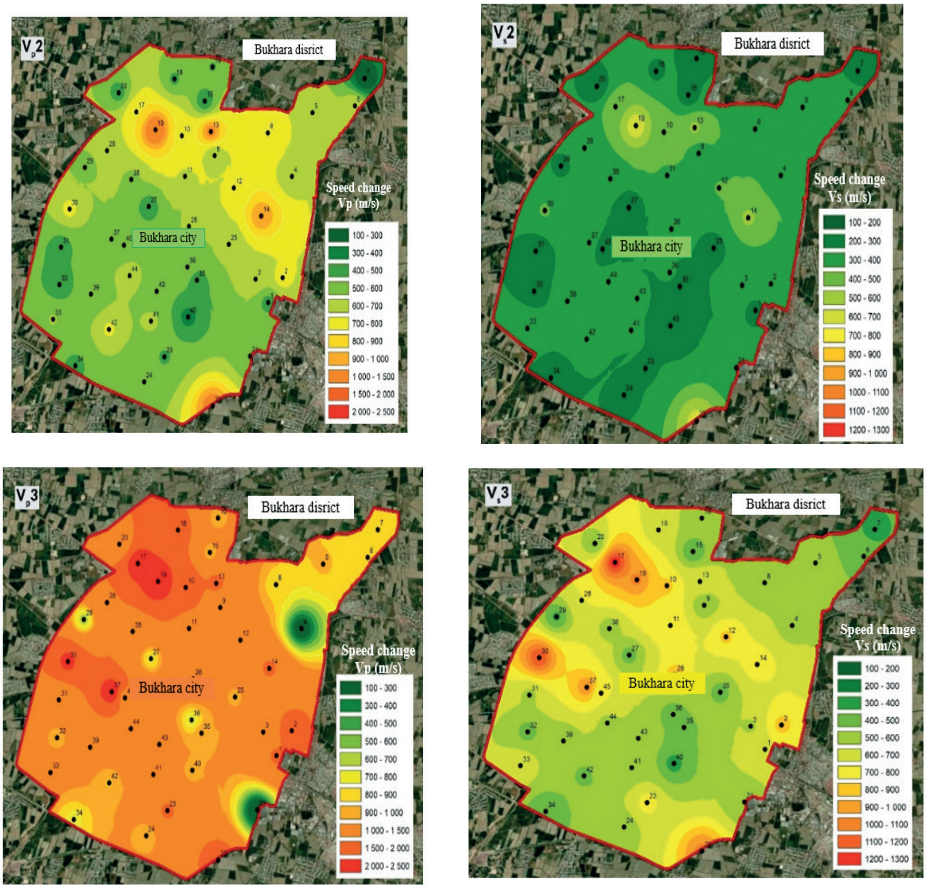


Figure 5. Distribution of shear and pressure wave velocities with depth (separated by seismicity)

Results and discussion. The thickness of Quaternary sedimentary layers reached the maximum value in the northeastern part of Bukhara city. Our instrumental studies also confirm this by the means of the defference in the values of the vibration amplitudes of the H/V spectra. To the southwest of the city, gravel-sandstone layers are close to the surface. It is known that gravel-sand fragments in rocks belong to the 2nd category according to the seismic properties of soils. Seismic wave velocities are observed at small values in the propagation fields of these soils. In addition, in the Central part of the city, i.e. in the Old city part, bedding soils is most common, in some places the thickness of bedding soils reaches 20 m. Because, the bedding soils belong to the category of seismically weak soils. It can be seen here that the fluctuations of the amplitude H/V spectra of the soils have large values. Data obtained from microseismic measurements are processed, and a 2D depth-dispersed velocities model of pressure and shear waves was created (Aktamov et al., 2025; Ismailov et al., 2025; Yusupov et al., 2021).

In 2D models, distribution of compressional and shear velocities at depth was divided into three seismic layers. Average speeds of soils can be determined through this model. From the determined average velocities, it will be possible to estimate the seismic condition of the soil (Aaqib et al., 2020) (Table 1).

Table 1 – Calculated values of compressional and shear wave velocities at depth

№	H_1(м)	V_{p1}(м/с)	V_{s1} (м/с)	H_2(м)	V_{p2}(м/с)	V_{s2}(м/с)	H_3(м)	V_{p3}(м/с)	V_{s3}(м/с)
1	-2,4	320	155	-14,5	460	265	-100	1560	683
2	-8,4	470	280	-18	741	400	-94	1866	836
3	-2,6	370	165	-16,2	676	385	-33,6	1015	590
4	-6	316	185	-18,5	625	355	-44,8	150	565
5	-8,3	280	162	-9	676	355	-27	911	525
6	-1,6	300	155	-16,3	695	380	-30,1	800	480
7	-5	305	165	-10	192	252	-69	810	362
8	-7,4	246	150	-10,4	780	365	-83	832	507
9	-7,6	270	160	-9	597	357	-78	1032	504
10	-5	400	210	-21,8	770	462	-100	1836	820
11	-1,8	452	232	-16,6	693	392	-50	1305	802
12	-3	470	237	-12	700	401	-35	1350	820
13	-7	410	210	-26,6	1060	524	-100	1590	682
14	-3,3	470	217	-14,9	1010	520	-44,8	1556	761
15	-4	304	152	-9	402	230	-71	895	396
16	-3	410	160	-11	495	222	-94,5	915	520
17	-1,2	370	175	-25	800	480	-100	2400	1275
18	-2,5	280	150	-13,2	482	280	-100	1700	637
19	-4	452	213	-24	1247	700	-100	2650	1025
20	-5,7	320	180	-8,5	450	200	-87	995	485
21	-5,7	270	150	-9,7	510	320	-83	81,5	500
22	-7,5	560	325	-27	1090	640	-100	1815	1030
23	-3	370	180	-13,3	490	290	-84	1580	750
24	-3,6	370	175	-15,8	505	275	-29	900	550
25	-5	320	150	-13	620	250	-100	950	455
26	-5,2	425	212	-10,3	610	340	-100	1500	860
27	-2	465	160	-10,3	435	222	-19,2	770	456
28	-4,4	285	150	-15,5	620	305	-84	1440	700
29	-3	380	150	-16,5	570	285	-63	640	380
30	-1,8	370	155	-20	730	410	-100	2150	1200

31	-6	400	180	-14	450	250	-100	1135	580
32	-3	370	205	-9	430	250	-25	933	460
33	-3,5	470	215	-14,2	605	385	-25	1100	690
34	-7,7	350	180	-13	480	250	-76	760	420
35	-3	380	160	-12,6	450	210	-92	950	480
36	-5,5	350	215	-12,3	600	330	-30	725	430
37	-5,3	450	230	-19	590	360	-100	2500	1000
38	-2,3	335	150	-13,3	580	350	-30	1040	540
39	-4	310	175	-18	520	340	-30	1050	515
40	-2	300	160	-8,4	360	210	-30	960	360
41	-5,4	405	250	-8	630	320	-30	1100	560
42	-5,7	260	155	-11	720	335	-70	890	480
43	-3	380	215	-15	515	325	-30	1270	600
44	-2,3	390	200	-16	675	320	-37	1150	575
45	-2,5	295	155	-12,5	500	256	-76	1285	700

In the city of Bukhara, mostly alluvial deposits are widespread, and these deposits can be divided into several parts, which are unevenly distributed over the city. Depending on the orientation of the ancient river beds from the southwest to the northeast, the flow directions are observed at several depths (Fig. 6-a,b).

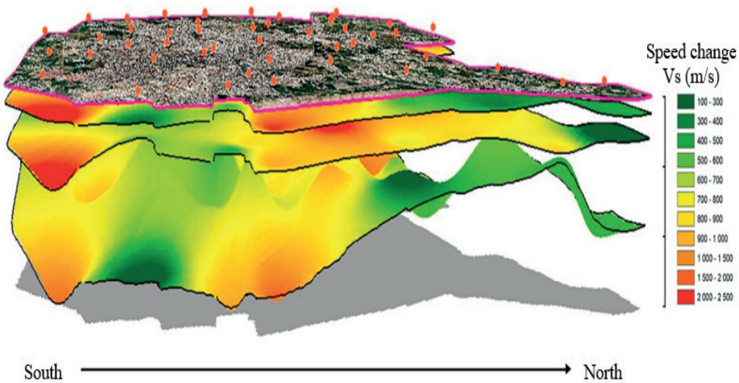


Figure 6a. A plot of the distribution of shear wave velocity by depth

The uneven distribution of wave speeds on the territory varies depending on the classification of alluvial and delluvial deposits, which belong to ancient river beds. Shear wave velocity (Vs), in the north-eastern and central as well as eastern parts of the region, mainly corresponds to second-class soils in terms of seismic (300-400 m/s) properties (Fig. 6b) (Lontsi et al., 2016; Pastén et al., 2016)

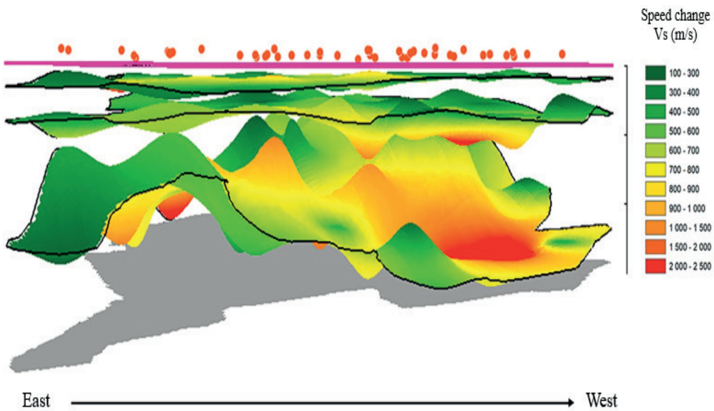


Figure 6b. A plot of the distribution of shear wave velocity by depth

The results of research conducted by geologists also confirm the opinion that the city of Bukhara is located in an ancient riverbed. Seismic observations are represented by large values (400-500 m/s) of shear wave velocity at small depths in the northern part of the city. Because, the northern part of the city of Bukhara increases towards the megasynclinal with a sharp change in the sediment cover with sorted alluvial rocks at small depths, while in the western part this depth increases and a sharp increase in seismic wave velocities (700-800 m/s) observed (Fig. 7ab).

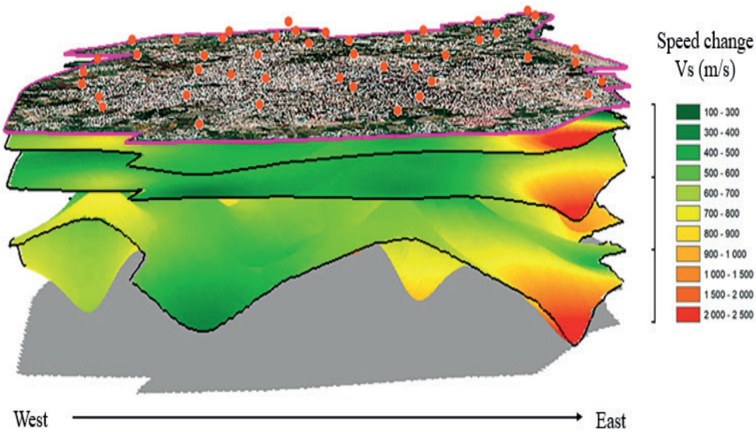


Figure 7a. A plot of the distribution of shear wave velocity by depth

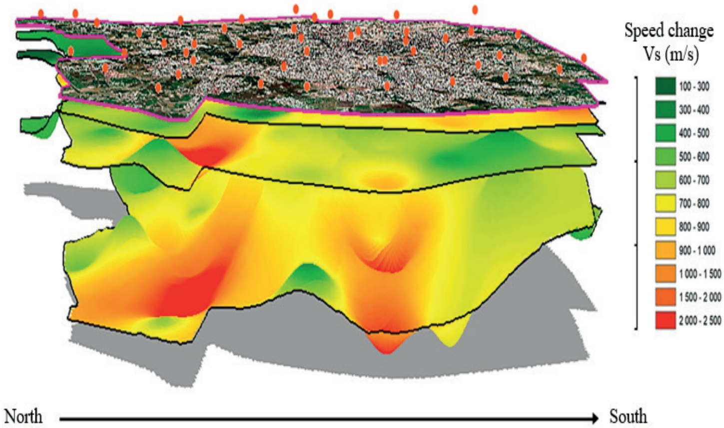


Figure 7b. A plot of the distribution of shear wave velocity by depth

In the layers located at depth (up to 100 meters), the increase in wave velocities changes in four directions in the submeridional direction. This change is closely related to the change of the ancient river bed. In this regard, it is essential to rely on a number of factors to restore geological conditions. These are: paying attention to the change of soil category in the construction of engineering structures on soil, the deformation state of parts filled with loose rocks during earthquakes in ancient river valleys, the construction of separate accelerograms for the foundation part of buildings and structures in accordance with the prevalence of second-class soil in the northern parts is important.

Analysis of microseismic vibrations in the city of Bukhara was carried out by observing changes in the seismic properties of soils in different parts of the city at different depths.

The first engineering-geological layer consists of bed soils represented by a sandy layer. They are 0.6 to 9 m thick in the central part of the studied area. It can also be seen in the 3D models that, the first seismic layers' Vs and Vp velocities have small values in the range of 0-8.4 m. In the old city part of the research area, the thickness of the bed soil layer has decreased to 2-5 m, while this in the vicinity of the old city at around 0-2 m. The upper 1.2-2.0 m, less than 3.0 m part contains new soils formed as a result of disposal of household and construction waste (Amendment №1 to KMK 2.02.01-98).

The second layer is represented by a thin layer of fine-grained sand and clay with loess-like sand and light brown, yellow, dark gray soils with lenses. They lie directly, mainly under the bed soil or at a depth of 0-6.5 m from the surface, with a thickness of 1 m to 11 m.

The third engineering-geological layer is represented by clays of the Quaternary period, which are found in the form of lenses and layers below the level of groundwater.

The fourth engineering-geological layer is represented by sands. This layer is spread over the entire area. Loose sands are found in the upper horizon, and dense sands are found at the border of the fifth layer (gravel-loess) at the base of the layer.

Engineering-geological data and microseismic data are compared. In this, the lithological composition of the layers and the wave permeability of the layers are considered.

Conclusion: The use of this research method as a cost-effective and convenient method for engineering works will give effective results for the economy of the country. In order to confirm the reliability of the method, it almost corresponded to the values obtained in the results of the seismic exploration works (MASW) measured in the area. Conducting geological-geophysical research in cities causes some difficulties due to various seismic noises and unfavorable conditions of several places. Analysis in the above-mentioned optimal options gives effective results for conducting measurement work in short and convenient conditions. The results are successfully completed in order to study the ground seismic conditions for the entire part of Bukhara city. Soil seismic conditions are characterized by uneven distribution of second and third class soils in the city. The central and northern parts of the city, as well as the southern and north-western parts, are represented by soils with high seismicity in terms of strength.

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