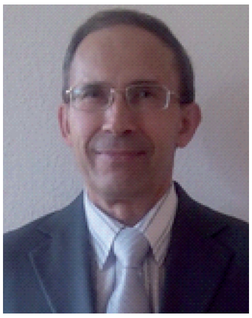
Doi: 10.33644/01003

УДК 624.046.3.:624.014.27.:624.074.4:725.36



MARIENKOV M. H.
Doctor of Engineering, Senior Researcher, Head of Department, SE "The State Research Institute of Building Constructions",
Kyiv, Ukraine
e-mail:n.maryenkov@ndibk.gov.ua
tel.: +38 (050) 415-36-03
ORCID: 0000-0002-7246-845X

DUNIN V. A.
Researcher, SE "The State Research Institute of Building Constructions",
Kyiv, Ukraine
e-mail: v.dunin@ndibk.gov.ua
tel.: +38 (044) 249-37-93
ORCID: 0000-0002-0370-0825

MARGVELASHVILI N.
PhD in Eng. Sc., Head of Department, Csiro Ocean and Atmosphere,
Hobart, Tasmania, Australia
e-mail: nugzar.margvelashvili@csiro.au
tel: +61(03) 6232 5142

FARENYUK G.G.
Doctor of Technical Sciences, Prof., Director, State Enterprise "The State Research Institute of Building Constructions",
Kyiv, Ukraine
e-mail: farenyuk@ndibk.gov.ua,
tel.: + 38 (044) 249-72-34,
ORCID: 0000-0002-5703-3976

BERCHUN Ya. O.
PG student, Department of Natural Resources, Institute of Telecommunications and Global Information Space of NAS of Ukraine,
Kyiv, Ukraine
e-mail: berchun93@gmail.com
tel.: +38 (050) 179-09-03
ORCID: 0000-0002-9373-2870

EXPERIMENTAL MONITORING AND DYNAMIC CERTIFICATION OF BUILDING STRUCTURES

ABSTRACT

Methods of building structures (BS) dynamic certification have been developed. The methods include: BS visual and vibrodynamic examination; recommendations for the repair and restoration; BS further operation. Determination of dynamic characteristics of building structures for their free fluctuations of low amplitude, which are disturbed by the influence of natural microseisms, includes: registration of BS fluctuations by means of highly sensitive (in our case, seismic) sensors; analysis of Fourier spectrum in order to allocate resonance peaks corresponding to various forms of free oscillations; obtaining of impulse realizations of the selected resonance peaks on each form of constructions optical oscillations by means of Fourier inversion. An example of the modern regulatory requirements application for the construction scientific and technical support and building structures monitoring for the pile foundation safe arrangement on a landslide hazardous building site in conditions of dense urban development in Kyiv during the installation of a Ø820 mm bored pile according to the pile field plan has been considered. Experimentally registered levels of vibration acceleration on the building foundation wall in the vertical and horizontal directions do not exceed 0.015 m/s², which is significantly lower than the minimum permissible values of vibration acceleration for the foundations of buildings with brick bearing walls 0,15 m/s². The research also

evaluated the presence of visible damage to the building in the available places and their possible development before and after piles placement. The condition of the plaster screed on a vertical crack in the house wall on the 8th floor, which was installed before the construction work start, after pile foundation installation has not changed – it remained undamaged.
KEYWORDS: monitoring, dynamic certification, acceleration, frequency, defects.

ЕКСПЕРИМЕНТАЛЬНИЙ МОНІТОРИНГ ТА ДИНАМІЧНА СЕРТИФІКАЦІЯ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ

АНОТАЦІЯ

Розроблені методи динамічної сертифікації будівельних конструкцій (БК). Методи включають: візуальне та вібродинамічне дослідження БК; рекомендації щодо ремонту та відновлення; подальша експлуатація БК. Визначення динамічних характеристик будівельних конструкцій для їх вільних коливань малої амплітуди, що порушуються впливом природних мікросейсмів, включає: реєстрацію коливань БК за допомогою високочутливих (у нашому випадку сейсмічних) датчиків; аналіз спектру Фур'є з метою виділення резонансних піків, що відповідають різним формам вільних коливань; отримання імпульсних реалізацій вибраних резонансних піків на кожній формі оптичних коливань конструкцій за допомогою інверсії Фур'є. Розглянуто приклад застосування сучасних нормативних вимог, щодо науково-технічного супроводу будівництва та моніторингу БК, для безпечного улаштування пальового фундаменту на зсувонебезпечній будівельній ділянці, в умовах ущільненої міської забудови в м. Києві, під час влаштування буронабивної палі Ø820 мм, згідно з планом пальового поля. Експериментально зареєстровані рівні віброприскорень на фундаментній стіні будівлі в вертикальному та горизонтальному напрямках не перевищують 0,015 м/с², що значно менше мінімально допустимих значень віброприскорень для фундаментів будівель з цегляними несучими стінами 0,15 м/с². При дослідженнях оцінювалась також наявність видимих ушкоджень в будівлі в доступних для цього місцях та їх можливий розвиток до і після влаштування палі. Стан гіпсового маяка на вертикальній тріщині в стіні будинку на 8-му поверсі, який був встановлений до початку будівельних робіт, після влаштування пальового фундаменту не змінився – він залишився неушкодженим.
КЛЮЧОВІ СЛОВА: моніторинг, динамічна сертифікація, прискорення, частота, дефекти

INTRODUCTION

The seismic risk is an unavoidable companion of our civilization and demands an adequate response. Thus, the buildings structures dynamic certification is a high priority step towards provision of the necessary and cost-effective level of constructions seismic resistance under conditions of obsolescence and physical deterioration, assessment of buildings and structures seismic vulnerability or their defects possible degree during the earthquakes of different intensity. The issue of BS dynamic certification and cost effectiveness of earthquake resistant construction have been considered in works by national and foreign researchers [1-21] and others. The general condition of the construction sites in Ukraine does not ensure safe living conditions for citizens and society due to the increased risk of emergencies. The increase in the buildings and constructions height, break with symmetric forms, and constant increase in the technogenic load on sites during the construction in conditions of dense urban development enhance the likelihood of disasters conditions.

First of all, it regards Kyiv where there are numerous examples of such violations:

1. In the center of Kyiv there have been another construction scandal regarding construction of "Elegant" residential development in dense urban development conditions on 118, Zhylianska Street [22]. At the beginning of construction process the neighboring five-storey house cracked during the pile driving, the tenants had to be resettled. As a result, an old five-story mansion and a one-story building next to it on 120-V Zhylianska Street was broken down and a huge trench was dug on this site. Residents of nearby houses are afraid that the walls of their houses will collapse – the cracks have already appeared on the upper floors [23].
2. Residents of houses number 3, 5, 5a and 7 on Lesia Ukrainka Blvd. and three more houses along Mechnikova Street were united by one problem - the construction in their yard. Houses are built on a landslide slope. Delicate balance can be disrupted by any intervention of construction equipment. Houses on Lesia Ukrainka Bvld. will simply slide down to Mechnikova Street [24].
3. On 7 Marianenka Lane a crack opening in the house walls coincides with the beginning of excavation for a residential complex on 9 and 11 Mechnikova Street. The state of the house was affected immediately by two construction sites – 9a and 11 Mechnikova Street and 12a Klovskyi Descent as well.

The above examples are just the tip of the iceberg of constantly increasing number of ground displacements and catastrophes across Ukraine both in terms of their number and in terms of economic losses scale. There is an acute need for monitoring and scientific and technical support for new constructions taking into account the implementation of the new regulatory documents requirements for soil accidents prevention in future [25].

Over the past 10 years the State Enterprise "The State Research Institute of Building Constructions" gave much attention to both the regulatory and methodological support and to construction monitoring systems implementation. During this time, a number of regulatory documents considering monitoring of building structures have been developed:

1. DBN B.1.2-5: 2007 "Scientific and technical support of construction sites" [26].
2. DBN B.1.2-12-2008 "Construction in conditions of dense urban development. Safety requirements" [27].
3. DBN B.1.2-14-2009 "General principles for ensuring safety and reliability of buildings, facilities, structures" [28].

All of the above documents were a basis for new final regulatory document DSTU-B B.1.2-17: 2016 "Guidance on scientific and technical monitoring of buildings and structures" [29], which was developed under scientific supervision of prof. Yu.I. Kaliukh along with a series of regulations for technical diagnostic systems for buildings and structures [30]. Construction regulations [9] include all major methodological instructions and developments made on the scientific and methodological basis as well as design and experimental development of monitoring systems of structures [26-28, 30-31] that were put into effect on 01.04.2017. Guidance [9] was developed in harmonic accordance with international construction standards fib [12]. In [29] as well as in the fib Report [32], the classification of monitoring systems of structures is the same (see Figure 1 [12]).

Theoretical and methodological issues of the design and organization of monitoring research are analyzed in the works of modern foreign scientists Sassa K., Casagli N., Catani F., Lu P., Mikoš M., Željko A. and others [33-38]. Among the Ukrainian scientists, one should note the researches by prof. O. Trofimchuk, Associate Member of NAS of Ukraine, and prof. I. Kaliukh concerning theoretical and methodological background of monitoring systems concept, their design and experimental development in practice in construction and geotechnics, as well as studies of their students aimed at the same issues: Kaliukh T. [39], Polevets'kyi V. [40], Klymenkov O. [41], Khavkin K. [42], et al.

According to these researches, the current certification methods can be nominally divided into three groups: method of expert assessment, calculation and analytical method, and method of technical diagnostics. Due to advantages and disadvantages peculiar to each of three methods, the relevant problems of certification can be reduced to two main issues. The first issue is a valid identification of criterion during assessment of seismic resistance of structures investigated. The second issue is an identification of required level of influence where dynamic structure of the building is investigated i.e. micro dynamic level under elastic stage of constructions operation or level of load relevant to the construction operation beyond the elasticity. Unfortunately, today there is no unique legal method for dynamic certification of structures in Ukraine. Hence, there is a need to improve test methods aimed at assessment of real seismic resistance including physical deterioration of the structures and it is an actual problem for Ukraine.

METHODS

We offer applicable method of certification and assessment of technical state of buildings and facilities. The method includes

- visual and vibrodynamic examination of buildings and facilities;
- development of calculation model and calculations with regard to actual seismicity of the area;
- comparative analysis of experimental and estimated data;
- recommendations for the repair and restoration and further operation of buildings and facilities.

Determination of dynamic characteristics of buildings and facilities in order to find free fluctuations of low amplitude, which are caused by the influence of natural microseisms includes the following steps:

- registration of fluctuations of the buildings and facilities with help of highly sensitive (in our case, seismic) sensors;
- calculation and analysis of Fourier spectrum in order to allocate resonance peaks corresponding to different forms of free oscillations; recording of impulse realizations of the selected resonance peaks on each form of optical oscillations of structures by means of Fourier inversion;
- Identification and graphic representation of different forms of oscillations.

BASIC MATERIAL

We would like to consider how up-to–date regulatory requirements are used for scientific and technical support and monitoring of structures [6-11] for safe arrangement of the pile foundation on a landslide prone construction site in conditions of dense urban development at the address 14, Pimonenka street, Kyiv in case of installation of a bored pile № 87 with a diameter of 820 mm in accordance with the plan of pile field. The working area with a well for the bored pile is at a distance of 18-20 m from the nine-storeyed residential brick building. The area of the construction site is below the level of the area of the adjacent building and there is a retaining wall made of concrete blocks being 5 m high on the boundary. The mutual location of the building, the retaining wall and the construction site is presented in Fig. 1

According to the present DBNs [26-31] the inspection of technical condition of the structures of the nine-storeyed building was performed in advance prior to drilling works, see (Fig. 1).

Figure 1 - Investigated building and retaining wall - View

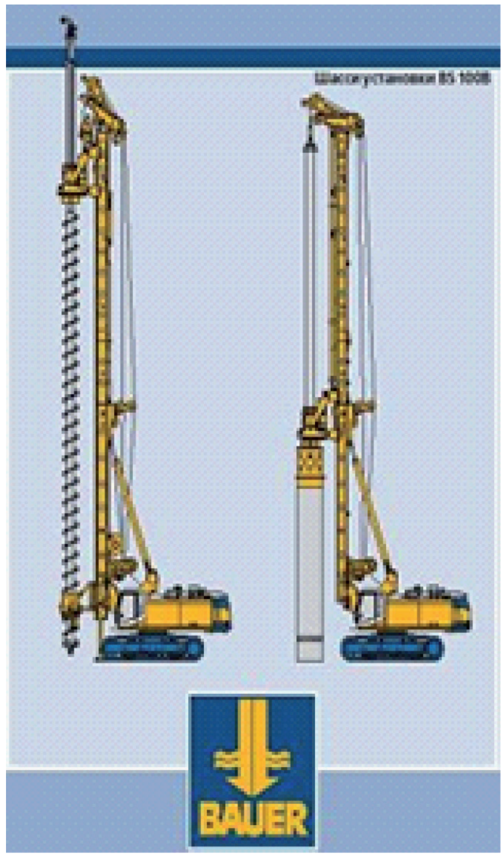


Figure 3 - Rotary drilling rig BG 40

Figure 2 - Chalky screed after the installation of the pile

Figure 4 - Construction site located near the building at 14, Pimonenko street (view from the flat on the 9th floor)

During the study of the technical condition of the structures, visible damage in the places available for this site and their possible development was assessed before the beginning of the works and during and after the installation of piles. The monitoring of the impact on building caused by drilling was monitored not only instrumentally, but also visually, by periodic observations during the arrangement of the bored pile № 87 with a diameter of 820 mm and with regard to the integrity of the chalky screed in a vertical crack in the bearing brick wall of the house at the 8th floor. The screed was installed in advance before the beginning of drilling (see Fig. 2).

Well drilling was performed by the BAUER 40 BG rotary drilling rig (Fig. 3). In the photo (Fig. 4) there is a view of the building investigated and the retaining wall alongside of the construction site. During the research period, one BAUER 40 BG rotary drilling rig (Fig. 3) worked on the site.

The vibration sensors were located on the foundation of the building (there were 3 vibration sensors) and oriented towards X, Z and Y directions (Fig. 5); two vibration sensors were located on the floor of the 9th floor of the building and were oriented towards X, Z or Y, Z directions (Fig. 6). The change in the orientation of the vibration sensors for the measurement of vibration acceleration was conducted in concert with the moment of their registration.

RESULTS

With the help of "Seismic monitoring" software [43] the initial experimental results were processed and represented in the table.

The values of vibration acceleration - typical and peak - of the foundation (sensors № 1, № 2 and № 3) and the last 9th floor of the building (sensors № 4 and №5) are given below.

CONCLUSIONS

The paper covers up-to–date regulatory requirements which are used for scientific and technical support and monitoring of structures [26-31] for safe arrangement of the pile foundation on a landslide prone construction site in conditions of dense urban development at the address 14, Pimonenka street, Kyiv in case of installation of a bored pile № 87 with a diameter of 820 mm in accordance with the plan of pile field.

Continuous monitoring of the piling process was conducted from 10.44 (time when the works started) to 17.56 (time when the works finished). The materials obtained from the experiments have shown:

1. The registered levels of vibration acceleration on the foundation wall of the building do not exceed 0.015 m / s² in the vertical and horizontal directions and this is considerably less than the minimum permissible values of vibration acceleration of the foundations of buildings with brick bearing walls which is 0,15 m / s² according to Table. 2 [44].
2. The registered levels of vibration acceleration at the 9th floor slab of the building do not exceed 0.004 m / s² in the vertical and horizontal directions and this is significantly lower than the permissible values of vibration

Figure 5 - Vibration sensors № 1, № 2 and № 3 for the registration of foundation oscillations oriented towards X, Z and Y directions

Figure 6 - Vibration sensors № 4 and № 5 for the registration of oscillations of the 9th floor of the building oriented towards X, Z or Y, Z directions

Table 1 - The values of vibration acceleration of the foundation - typical and peak

№	Time of moni-toring	Grade, soil	Max values of vibration accelerations	Drilling practice
1	2	3	4	5
1	10.44	0 m; Clay	№ 1 - 0.0005, 0,002-0.004 (X)	Record at silence regime
			№ 2 - 0.0005, 0,002-0.004 (Z)	
			№ 3 - 0.0002, 0,002-0.004 (Y)	
			№ 4 - 0.0001, 0,002-0.003 (X)	
			№ 5 - 0.0005, 0,002-0.004 (Z)	
2	10.59	0 m; Clay	№ 1 - 0,002 -0,004 (X)	Start of drilling Drilling of a well
			№ 2 - 0,001 -0,005 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,001 -0,005 (X)	
			№ 5 - 0,001 -0,002 (Z)	
			№ 2 - 0,001 -0,003 (Y)	
			№ 3 - 0,001 -0,002 (Z)	
			№ 4 - 0,001 -0,002 (X)	
			№ 5 - 0,0005-0,001 (Z)	
3	11:18	4-5 m; Clay	№ 1 - 0,001 -0,003 (X)	Drilling of a well
			№ 2 - 0,001 -0,003 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,001 -0,002 (X)	
			№ 5 - 0,0005 (Z)	
4	11:20	6-7 m; Clay	№ 1 - 0,001 -0,003 (X)	Drilling of a well
			№ 2 - 0,001 -0,006 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 -0,002 -0,0025 (X)	
			№ 5 -0,0005-0.001 (Z)	
5	11:22	8 m; Clay	№ 1 - 0,001 -0,002 (X)	Microseismic background. Lengthening of tube timbering
			№ 2 - 0,001 -0,003 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,001 -0,002 (X)	
			№ 5 - 0,0005-0,001 (Z)	
6	11:28	8 m; Clay	№ 1 - 0,002 -0,001 (X)	Motion of a drilling rig with tube timbering
			№ 2 - 0,001 -0.0035 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 -0,0015-0,001 (X)	
			№ 5 - 0,0005 (Z)	

Table 1 continued

1	2	3	4	5
7	11:40	9-10 m, Clay	№ 1 - 0,0015-0,004 (X)	Tube timbering spudding and next drilling
			№ 2 - 0,001 -0,005 (Z)	
			№ 3 - 0,002 -0,003 (Y)	
			№ 4 - 0,001 -0,005 (X)	
			№ 5 - 0,002-0,0005 (Z)	
8	11:56	14-16 m, Clayed sand	№ 1 - 0,001 -0,002; 0,006 (X)	Drilling of a well
			№ 2 - 0,001 -0,002; 0,006 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,001-0,0015 (X)	
			№ 5 - 0,0003 (Z)	
9	12:05	16 m, Clayed sand	№ 1 - 0,001 – 0,0015 (X)	Microseismic background. Lengthening of tube timbering
			№ 2 - 0,0005; 0,002 (Z)	
			№ 3 - 0,0005 (Y)	
			№ 4 - 0,0005; 0,003 (X)	
			№ 5 - 0,0005 (Y)	
10	12.50	17-18 m, Clayed sand	№ 1 - 0,006 -0,008 (X)	Drilling of a well
			№ 2 - 0,004; 0,001 -0,003 (Z)	
			№ 3 - 0,001 -0,003; 0,015 (Y)	
			№ 4 - 0,0035 (X)	
			№ 5 - 0,0005; 0,0015 (Z)	
11	12:54	18-19 m,Clayed sand	№ 1 - 0,006 (X)	Drilling of a well
			№ 2 - 0,001 -0,003; 0,004 (Z)	
			№ 3 - 0,0025 – 0,0015; 0,005 (Y)	
			№ 4 - 0,002 -0,004 (X)	
			№ 5 - 0,0005; 0.003 (Z)	
12	12:56	19-20 m, Clayed sand	№ 1 - 0,006 (X)	Drilling of a well
			№ 2 - 0,002 -0,005 (Z)	
			№ 3 – 0,0025 -0,003; 0.006 (Y)	
			№ 4 - 0,0025 (X)	
			№ 5 - 0,0025 (Z)	
13	13:22	22 m, Watered clayed sand	№ 1 - 0,001 -0,003 (X)	Drilling of a well
			№ 2 - 0,001 -0,006 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,001 -0,0025 (X)	
			№ 5 - 0,0005 -0,003 (Z)	
14	13:36	24-25 m, Watered clayed sand, Red clay	№ 1 - 0,001 -0,0015 (X)	Drilling of a well
			№2 - 0,0005; 0,002 (Z)	
			№ 3 - 0.0008 (Y)	
			№ 4 - 0,0005 –0,002 (X)	
			№ 5 - 0,004; 0,0005 (Z)	

Table 1 continued

1	2	3	4	5
15	14:04	28-30 m, Hard marl	№ 1 - 0,001 – 0,002 (X)	Drilling of a well
			№ 2 - 0,001 – 0,002 (Z)	
			№ 3 - 0,001 – 0,002 (Y)	
			№ 4 - 0,0025 -0,001 (X)	
			№ 5 - 0,0003 (Z)	
16	14:32	32-33 m, Waterlogged marl, Hard clay	№ 1 - 0,001 – 0,004 (X)	Drilling of a well
			№ 2 - 0,0005 – 0,003 (Z)	
			№ 3 - 0,001 -0,002 (Y)	
			№ 4 - 0,0025 -0,001 (X)	
			№ 5 - 0,0005 (Z)	
17	14:43	35-36 m, Compacted marl	0,0008 – 0,0015 (X)	Drilling of a well
			0,001 – 0,002 (Z)	
			0,001 (Y)	
			0,001; 0,002 (X)	
			0,0005 (Z)	
18	15:13	37-38 m, Marl	0,001 – 0,002; 0,004 (X)	Drilling of a well
			0,001– 0,0015; 0,005 (Z)	
			0,001 – 0,0015; 0,003 (Y)	
			0,001; 0,002 (X)	
			0,0035 (Z)	
19	15:26	38-39,5 m, Marl	0,001 – 0,002 (X)	Drilling of a well
			0,001– 0,002 (Z)	
			0,001 – 0,0015 (Y)	
			0,001; 0,002 (X)	
			0,0025; 0,0005 (Z)	
20	17.25	39.5 -35 m	№ 1 - 0,001 – 0,002 (X)	Drilling of a well with concrete at the point of 39.5 - 35 m
			№ 2 - 0,001– 0,004; 0,006 (Z)	
			№ 3 - 0,001 – 0,0015 (Y)	
			№ 4 - 0,0015; 0,003 (X)	
			№ 5 - 0,0005 (Z)	
21	17.35	39,5 m	№ 1 -0,0005 – 0,001 (X)	Lifting of tube timbering from the well at 39,5 m depth
			№ 2 - ,0005 (Z)	
			№ 3 - 0,0005 – 0,0008 (Y)	
			№ 4 - 0,0015; 0,0005 (X)	
			№ 5 - 0,0005 (Z)	
22	17.41	31 -23 m	№ 1 - 0,0015 – 0,001 (X)	Filling of a well with concrete at the point of 31 - 23 m
			№ 2 - 0,0012 – 0,0003 (Z)	
			№ 3 - 0,0015 – 0,0003 (Y)	
			№ 4 0,0025- 0,0008 (X)	
			№ 5 - 0,0003 (Z)	
23	17.56	31,5 m	№ 1 - 0,001 – 0,0018 (X)	Lifting of tube timbering from the well at 31,5 m depth
			№ 2 - 0,001 – 0,0003 (Z)	
			№ 3 - 0,001 – 0,0002;0,006(Y)	
			№ 4 - 0,001 - 0,002 (X)	
			№ 5 - 0,0003 (Z)	

acceleration of high-rise buildings which is 0.08 m / s² in according with para.7.2 [45].

3. In the research, the presence of visible damages to the building in the available places and possible development before and after pile installation was also assessed. Their development was evaluated according to a plaster screed on a vertical crack in the wall of the building. The state of the chalky screed on the vertical crack at the8th floor was identified before the beginning of vibration dynamic tests on 02/15/2017. At the moment of the research on 02/21/2017 and after the installation of a concrete pile and next arrangement of pile foundation the state of the chalky screed has not changed. It remained undamaged. This is shown in the photo (Fig. 2).
4. Based on the above mentioned, it is necessary to carry out arrangement of pile foundation in accordance with the relevant technological procedures during the operation of the BAUER 40 BG rotary drilling rig (see Fig. 3-4).
5. For the control of quality of pile concreting, updated theoretical and numerical developments and technical means of the SE "SRIBC" [46] can be used.

REFERENCES

1. Alonso-Rodriguez, A., Nikitas, N., Knappett, J., Kampas, G., Anastasopoulos, I., & Fuentes, R. (2018). System identification of tunnel response to ground motion considering a simplified model. Frontiers in Built Environment, 4, 1-11.
2. Balducci, M., Regni, R., Buttiglia, S., Piccioni, R., Venanti, L.D., Casagli, N., & Gigli, G. (2011). Design and built of a ground reinforced embankment for the protection of a provincial road (Assisi, Italy) against rockslide. Proc. XXIV Conv. Naz. Geotecnica, AGI, Napoli, 22th- 24th June 2011.
3. Barla, M., Antolini, F., & Dao, S. (2014). Il monitoraggio delle frane in tempo reale. Strade e Autostrade, 107, 154–157.
4. Borja, R.I., White, J.A., Liu, X.Y., & Wu, W. (2011). Factor of safety in a partially saturated slope inferred from hydro-mechanical continuum modeling. International Journal for Numerical and Analytical Methods in Geomechanics, 63(2), 140-154.
5. Casagli, N., Catani, F., Del Ventisette, C., & Luzi, G. (2010). Monitoring, prediction, and early warning using ground-based radar interferometry. Landslides, 7(3), 291–301.
6. Frodella, W., Ciampalini, A., Bardi, F., Salvatici, T., Di Traglia, F., Basile, G., & Casagli, N. (2018). A method for assessing and managing landslide residual hazard in urban areas. Landslides, 15(2), 183-197.
7. Ginzburg, L., & Shvets, V. (1987). Soil dynamics and mechanics guide. Kyiv: Budivelnyk.
8. Gomilko, A., Savitskii, O., & Trofymchuk, O. (2016). Dynamics of porous elastic saturated fluid environments. Kyiv: Naukova Dumka.
9. Highland, L., & Bobrowsky, P. (2008). The Landslide Handbook—A Guide to Understanding Landslides. Reston, Virginia: U.S. Geological Survey Circular.
10. Intrieri, E., Gigli, G., Gracch, T., Nocentini, M., Lombardi, L., Mugnai, F. ... Casagli, N. (2018). Application of an ultra-wide band sensor-free wireless network for ground monitoring. Engineering Geology, 238, 1-14.
11. Trofymchuk, O., Kaliukh, I., Silchenko, K., Berchun, V., Kaliukh, T., & Berchun, Y. (2017). Mitigation of landslide hazards in Ukraine under the guidance of ICL: 2009 –2016 (IPL 153&191). 4th World Landslide Forum, Ljubljana, Slovenia, EU, 29 May-2 June, 2017.
12. Kaliukh, I., Senatorov, V., Khavkin, O., Kaliukh, T., & Khavkin, K. (2013). Experimentally-analytical researches of the technical state of reinforce-concrete constructions for defence from landslide's pressure in seismic regions of Ukraine. International Federation for Structural Concrete (fib) symp., Tel-Aviv, 22 -24 April 2013.
13. Lacasse, S. (2013). Terzaghi Oration Protecting society from landslides – the role of the geotechnical engineer. 18th intern. conf. on Soil Mechanics and Geotechnical Engineering, Paris, 2-6 September 2013.
14. Lollino, G., & Chiara, A. (2006). UNESCO World Heritage sites in Italy affected by geological problems, specifically landslide and flood hazard. Landslides, 3(4), 311-321.
15. Martinelli, M., Burghignoli, A., & Callisto, L. (2016). Dynamic response of a pile embedded into a layered soil. Soil Dynamics and Earthquake Engineering, 87, 16-28.
16. Shokrabadi, M., Burton, H.V., & Stewart, J.P. (2018). Impact of Sequential Ground Motion Pairing on Mainshock-Aftershock Structural Response and Collapse Performance Assessment. Structural Engineering, 144 (10): 04018177.
17. Tsytovich, N. (1963). Soil mechanics. Moscow: State Publishing House of Literature on Building, Architecture and Building Materials.
18. Trofymchuk, O., Kaliukh, I., & Berchun, V. (2017). Landslide stabilization in building practice: methodology and case study from autonomic Republic of Crimea. 4th World Landslide Forum, Ljubljana, Slovenia, EU,

29 May-2 June, 2017. Workshop on World Landslide Forum. Springer, Cham, 587-595.
19. Bases and foundations of buildings and structures. Main principles of design: DBN V.2.1-10:2009 (2009).
20. Construction norms and rules. Foundations for machines with dynamic loads: SNiP 2.02.05:87. (1988).
21. Wang, Y., & Rathje, E.M. (2018). Application of a Probabilistic Assessment of the Permanent Seismic Displacement of a Slope. Journal of Geotechnical and Geoenvironmental Engineering, 144 (6): 04018034.
22. Don't construct any more, but sell. Top-10 illegal housing estates in Kyiv. Retrieved from http://eveningkiev.com/article/33946
23. Property developers destroy old historical buildings in Kyiv Centre. Retrieved from https://censor.net.ua/photo_news/254614/v_tsentre_kieva_zastroyischiki_rushat_starinnye_doma_foto
24. Pechersk. New housing estate on hazardous slope: authority, greed, batts and landslides. Retrieved from: https://censor.net.ua/resonance/166/pechersk_novostroyi_na_opasnom_sklone_vlast_ jadnost_bity_i_opolzni_viktoriya_vladina_dlyatsenzornet
25. Cracked buildings in Kyiv can count just on installation of "indicators". Retrieved from http://eveningkiev.com/article/36152
26. Scientific and technical support of construction projects: DBN V.1.2-5:2007. (2008).
27. Construction in dense urban development conditions. Safety requirements: DBN V.1.2-12-2008. (2009).
28. General principles for ensuring the buildings, facilities, building structures and bases reliability and structural safety: DBN V.1.2-14-2009.
29. Kaliukh, I., Trofymchuk, O., Berchun, Y. et al. (2017). Guidance on scientific and technical monitoring of buildings and structures: DSTU-N B V.1.2-17:2016 (2017). Kyiv: Minrehionbud.
30. Computer-aided test systems of building constructions. Common specifications: DSTU B V.2.6–25:2003. (2003).
31. Buildings and structures. Design of high-rise residential and public buildings. DBN V.2.2-24:2009. (2009).
32. International Federation for Structural Concrete (fib). Task Group 5.1. (2003). Monitoring and safety evaluation of existing concrete structures. State of art report.
33. Sassa, K. (2005). Landslides: Risk analysis and sustainable disaster management. Retrieved from http://www.ebook3000.com/Kyoji-Sassa-Landslides-Risk-Analysis-and-Sustainable-Disaster-Management-147509.html.
34. Casagli, N, Catani, F, Del Ventisette, C, & Luzi, G (2010). Monitoring, prediction, and early warning using ground-based radar interferometry. Landslides, 7(3), 291–301.
35. Pieraccini, M, Casagli, N, Luzi, G, Tarchi, D, Mecatti, D, Noferini, L, & Atzeni, C. (2003). Landslide monitoring by ground-based radar interferometry: a field test in Valdarno (Italy). Int J Remote Sens, 24(6), 1385–1391.
36. Casagli, N., Tofani, V., Ciampalini, A., Raspini, F., Lu, P., & Morelli, S. (2018). TXT-tool 2.039-3.1: Satellite Remote Sensing Techniques for Landslides Detection and Mapping. In: Sassa K. et al. (Eds.) Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools (pp. 235–254). Cham: Springer.
37. Hübl, J., & Mikoš, M.. (2018). TXT-tool 2.386-1.2: Practice Guidelines on Monitoring and Warning Technology for Debris Flows. In: Sassa K. et al. (Eds.) Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools (pp. 567-585). Cham: Springer.
38. Ardanas, S.M., Krkač, M., Gazibara, S.B., Komac, M., Sečanj, M., & Arbanas, Ž. (2013). TXT-tool 2.385-1.1 A comprehensive landslide monitoring system: The Kostanjek landslide, Croatia. Retrieved from https://scholar.google.fr/citations?view_op=view_citation&hl=ru&user=7eoSoYYAAAAJ&citation_for_view=7eoSoYYAAAAJ:D03iK_w7-QYC
39. Kaliukh, T. (2011). Assessment of stress condition of landslide hazardous slopes in seismic loads conditions. (Doctor's thesis). Kyiv.
40. Polevetskyi, V. (2010). Regional features of landslide protection structures and landslide hazardous slopes in Chernivtsi Oblast. (Doctor's thesis). Kyiv: NDIBK.
41. Klimenkov, O., & Berchun, Y. (2016). Theoretical and methodological and practical aspects of buildings and landslide hazardous areas monitoring. 15th International scientific and practical conference "Modern information technologies of environmental safety management, nature management, emergency actions". Kyiv, Pushcha-Vodytsia, 3-6.10.2016. Kyiv: ITGIP NASU.
42. Khavkin, K. (2015). Landslide hazard and stress-strain state of landslide protection structures in seismically hazardous regions of Ukraine (the case of Bukovyna). (Doctor's thesis). Kyiv: NDIBK.
43. Vibrational security. General requirements: DSTU GOST 12.1.012: 2008. (2009).
44. Operator's Guide: "Seismomonitoring" multichannel measuring system (version 1.0). (2009). Kyiv: Kyiv National Technical University of Ukraine "Kyiv Polytechnic Institute". Scientific and Technical Center "NPP Technical Equipment Diagnostics".

Management program.
45. Rate making of structures vibration in the USSR and abroad, 1. (1990). Moscow.
46. Farenyuk, G., Kaliukh, I., Farenyuk, E., Kaliukh, T., Berchun, Y., & Berchun, V. (2017). Experimental and theoretical diagnostics of ferroconcrete piles base on reflection of longitudinal and transverse waves. International fib symposium "High tech concrete: Where technology and engineering meet!" Maastricht, The Netherlands, 12 – 14 June, 2017.

БІБЛІОГРАФІЧНИЙ СПИСОК

1. Alonso-Rodriguez A., Nikitas N., Knappett J., Kampas G., Anastasopoulos I., & Fuentes R. System identification of tunnel response to ground motion considering a simplified model. Frontiers in Built Environment. 2018. 4. C. 1-11.
2. Balducci M., Regni R., Buttiglia S., Piccioni R., Venanti L.D., Casagli N., & Gigli G. Design and built of a ground reinforced embankment for the protection of a provincial road (Assisi, Italy) against rockslide: proc. XXIV Conv. Naz. Geotecnica, AGI, Napoli, 22th- 24th June 2011.
3. Barla M., Antolini F., & Dao S. Il monitoraggio delle frane in tempo reale. Strade e Autostrade. 2014. 107. P. 154–157.
4. Borja R.I., White J.A., Liu X.Y., & Wu W. Factor of safety in a partially saturated slope inferred from hydro-mechanical continuum modeling. International Journal for Numerical and Analytical Methods in Geomechanics. 2011. 63(2). P. 140-154.
5. Casagli N., Catani F., Del Ventisette C., & Luzi G. Monitoring, prediction, and early warning using ground-based radar interferometry. Landslides. 2010. 7(3). P. 291–301.
6. Frodella W., Ciampalini A., Bardi F., Salvatici T., Di Traglia F., Basile G., & Casagli N. A method for assessing and managing landslide residual hazard in urban areas. Landslides. 2018. 15(2). P. 183-197.
7. Гинзбург Л., Швец В. Справочник по динамике и механике грунтов. Київ: Будівельник, 1987.
8. Гомилко А., Савицкий О., Трофимчук А. Динамика пористоупругих насыщенных жидкостью сред. Київ: Наукова думка, 2016.
9. Highland L., & Bobrowsky P. The Landslide Handbook—A Guide to Understanding Landslides. 2008. Reston, Virginia: U.S. Geological Survey Circular.
10. Intrieri E., Gigli G., Gracch T., Nocentini M., Lombardi L., Mugnai F. ... Casagli, N. Application of an ultra-wide band sensor-free wireless network for ground monitoring. Engineering Geology. 2018. 238. P. 1-14.
11. Trofymchuk O., Kaliukh I., Silchenko K., Berchun V., Kaliukh T., & Berchun Y. Mitigation of landslide hazards in Ukraine under the guidance of ICL: 2009 –2016 (IPL 153&191): 4th World Landslide Forum, Ljubljana, Slovenia, EU, 29 May-2 June, 2017.
12. Kaliukh I., Senatorov V., Khavkin O., Kaliukh T., & Khavkin K. Experimentally-analytical researches of the technical state of reinforce-concrete constructions for defence from landslide's pressure in seismic regions of Ukraine: International Federation for Structural Concrete (fib) symp., Tel-Aviv, 22 -24 April 2013.
13. Lacasse S. Terzaghi Oration Protecting society from landslides – the role of the geotechnical engineer: 18th intern. conf. on Soil Mechanics and Geotechnical Engineering, Paris, 2-6 September 2013.
14. Lollino G., & Chiara A. UNESCO World Heritage sites in Italy affected by geological problems, specifically landslide and flood hazard. Landslides. 2006. 3(4). P. 311-321.
15. Martinelli M., Burghignoli A., & Callisto L. Dynamic response of a pile embedded into a layered soil. Soil Dynamics and Earthquake Engineering. 2016. 87. P. 16-28.
16. Shokrabadi M., Burton H.V., & Stewart J.P. Impact of Sequential Ground Motion Pairing on Mainshock-Aftershock Structural Response and Collapse Performance Assessment. Structural Engineering. 2018. P. 144 (10): 04018177.
17. Цытович Н. Механика грунтов. Москва: Государственное издательство литературы по строительству, архитектуре и строительным материалам, 1963.
18. Trofymchuk O., Kaliukh I., & Berchun V. Landslide stabilization in building practice: methodology and case study from autonomic Republic of Crimea: 4th World Landslide Forum, Ljubljana, Slovenia, EU, 29 May-2 June, 2017. Workshop on World Landslide Forum. Springer, Cham, 587-595.
19. Основи і фундаменти будівель та споруд. Основні принципи проектування: ДБН.В.1-10:2009.
20. Строительные нормы и правила. Фундаменты машин с динамическими нагрузками: СНиП 2.02.05:87.
21. Wang Y., & Rathje E.M. Application of a Probabilistic Assessment of the Permanent Seismic Displacement of a Slope. Journal of Geotechnical and Geoenvironmental Engineering. 2018. 144 (6): 04018034.
22. Уже не строят, но еще продают. Топ-10 незаконных ЖК столицы. ULR: http://

eveningkiev.com/article/33946
23. В центре Киева застройщики рушат старинные дома. ULR: https://censor.net.ua/photo_news/254614/v_tsentre_kieva_zastroyischiki_rushat_starinnye_doma_foto
24. Печерск. Новострой на опасном склоне: власть, жадность, биты и оползни ULR: https://censor.net.ua/resonance/166/pechersk_novostroyi_na_opasnom_sklone_vlast_jadnost_bity_i_opolzni_viktoriya_vladina_dlyatsenzornet
25. Треснувшие столичные дома могут рассчитывать только на установку «маячков». ULR: http://eveningkiev.com/article/36152
26. Науково-технічний супровід будівельних об'єктів: ДБН.В.1.2-5:2007.
27. Будівництво в умовах ущільненої забудови. Вимоги безпеки: ДБН.В.1.2-12-2008.
28. Загальні принципи забезпечення надійності та конструктивної безпеки будівель, споруд, будівельних конструкцій та основ: ДБН.В.1.2-14-2009.
29. Калюх Ю., Трофимчук О., Берчун Я. та ін.. Настанова щодо науково-технічного моніторингу будівель і споруд: ДСТУ-Н Б В.1.2-17:2016 Kyiv: Minrehion-bud. 2017.
30. Автоматизовані системи технічного діагностування будівельних конструкцій. Загальні технічні вимоги: ДСТУ Б В.2.6–25:2003.
31. Будинки і споруди. Проектування висотних житлових і громадських будинків. ДБН.В.2.2-24:2009.
32. International Federation for Structural Concrete (fib). Task Group 5.1. Monitoring and safety evaluation of existing concrete structures. State of art report. 2003.
33. Sassa K. Landslides: Risk analysis and sustainable disaster management. 2005. ULR: http://www.ebook3000.com/Kyoji-Sassa-Landslides-Risk-Analysis-and-Sustainable-Disaster-Management-147509.html.
34. Casagli N, Catani F, Del Ventisette C, & Luzi G. Monitoring, prediction, and early warning using ground-based radar interferometry. Landslides. 2010. 7(3). P. 291–301.
35. Pieraccini M, Casagli N, Luzi G, Tarchi D, Mecatti D, Noferini L, & Atzeni C. Landslide monitoring by ground-based radar interferometry: a field test in Valdarno (Italy). Int J Remote Sens. 2003. 24(6). P. 1385–1391.
36. Casagli N., Tofani V., Ciampalini A., Raspini F., Lu P., & Morelli S. TXT-tool 2.039-3.1: Satellite Remote Sensing Techniques for Landslides Detection and Mapping. In: Sassa K. et al. (Eds.) Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools. 2018. P. 235–254. Cham: Springer.
37. Hübl J., & Mikoš M.. TXT-tool 2.386-1.2: Practice Guidelines on Monitoring and Warning Technology for Debris Flows. In: Sassa K. et al. (Eds.) Landslide Dynamics: ISDR-ICL Landslide Interactive Teaching Tools. 2018. P. 567-585). Cham: Springer.
38. Ardanas S.M., Krkač M., Gazibara S.B., Komac M., Sečanj M., & Arbanas Ž. TXT-tool 2.385-1.1 A comprehensive landslide monitoring system: The Kostanjek landslide, Croatia. 2013. ULR: https://scholar.google.fr/citations?view_op=view_citation&hl=ru&user=7eoSoYYAAAAJ&citation_for_view=7eoSoYYAAAAJ:D03iK_w7-QYC
39. Калюх Т. Оцінка напруженого стану зсувних небезпечних схилів в умовах сейсмічних навантажень: дис. докт. техн. наук, Київ, 2011.
40. Полевецький В. Регіональні особливості споруд для захисту зсувів та небезпечних зсувних схилів Чернівецької області:дис. докт. техн. наук. Київ: НДІБК, 2010.
41. Klimenkov O., & Berchun Y. Theoretical and methodological and practical aspects of buildings and landslide hazardous areas monitoring: 15th International scientific and practical conference "Modern information technologies of environmental safety management, nature management, emergency actions". Kyiv, Pushcha-Vodytsia, 3-6.10.2016. Kyiv: ITGIP NASU.
42. Калюх К. Небезпека зсувів та напружений стан захисних споруд у сейсмічно небезпечних регіонах України (на прикладі Буковини): дис. докт. техн. наук). Київ: НДІБК, 2015.
43. Вібраційна безпека. Загальні вимоги: ДСТУ ГОСТ 12.1.012: 2008.
44. Operator's Guide: “Seismomonitoring” multichannel measuring system (version 1.0). 2009. Kyiv: Kyiv National Technical University of Ukraine "Kyiv Polytechnic Institute". Scientific and Technical Center "NPP Technical Equipment Diagnostics". Management program.
45. Нормирование вибраций конструкций в СССР и за рубежом, 1. Москва. 1990.
46. Farenyuk G., Kaliukh I., Farenyuk E., Kaliukh T., Berchun Y., & Berchun V. Experimental and theoretical diagnostics of ferroconcrete piles base on reflection of longitudinal and transverse waves: International fib symposium “High tech concrete: Where technology and engineering meet!” Maastricht, The Netherlands, 12 – 14 June, 2017.

The paper was received on 12 Dec 2019