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ANALYSIS OF DAMAGE TO OBJECTS FROM THE INFLUENCE OF SLIDING SOILS

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Abstract. *The article presents the classification of damage to objects located on subsiding soils, which was developed based on the results of the analysis of scientific research conducted using the complex method of geodetic observations of deformations of the earth's surface and supporting structures of 273 residential buildings, as well as buildings of the Kherson State Agrarian and Economic of the university, which are located on sites with the above-mentioned properties soils*

The analysis showed that the degree of damage depends not only on the discharge, dimensions, structural features, technical condition of the building or structure, the nature of the object's operation, but also on the location of the subsidence hopper under it.

The use of the developed observation method makes it possible to fully determine the causes and negative factors of deformations on the earth's surface, as well as in the load-bearing structures of buildings and structures, and to develop a set of measures to preserve the normal operational quality of objects during the *active stage of the process of soil subsidence and horizontal movements the earth's surface.*

To clarify the nature of deformations in buildings and structures located in different zones of subsidence, it is necessary to continue research in other regions of the country.

Key words: *deformation of the earth's surface, deformation of load-bearing structures, operational properties, subsidence funnel*.

Topicality. Alluvial soils, represented mainly by rocks of the loess cover, occupy about 350 thousand km ^{2} of its entire area on the territory of Ukraine.

Alluvial loess soils have high porosity (up to 60%). In natural conditions with low humidity, loess soils have considerable strength and are a reliable foundation for buildings and structures. But when the soil is moistened to the so-called critical humidity, subsidence occurs, which is accompanied by additional uneven subsidence or lowering of the day surface of the earth [1].

During the inspection of objects built on subsiding soils that are subject to compaction, subsidence and displacement of the earth's surface are most often recorded, which, in turn, causes stress and deformation of the main load-bearing structures of buildings - foundations, walls and ceilings. Therefore, the forecast of expected damage to buildings, structures and engineering communications, taking into account the influence of subsoil soaking, is an urgent scientific and technical task.

Analysis of recent research and publications. Subsiding soils, in accordance with DSTU B.V.2.1-2-96, include dusty -clay varieties of dispersed sedimentary mineral soils, which give additional deformations during soaking and constant external loading and loading from the soil's own weight - subsidence, compaction of the soil, which occur due to changes in its structure.

As for the loess soil on the territory of Ukraine, according to researchers V. P. Ananyev, P. K. Zamoriya, and V. F. Krayev, it is of aeolian -glacial origin. Loess soils, as one of the main types of alluvial rocks, are widely distributed throughout the territory of Ukraine.

The influence of various factors on the strength properties of loess soils began to be studied as early as the 19th century, but even today this problem has not lost its relevance. By the end of the 20th century hypotheses about the origin of this property were formulated and a huge amount of experimental material was accumulated.

Analysis of individual factors and practical recommendations for specific objects can be found in the publications of the following authors: R. Lamperti, V.B. Shvets [2], V. Sukhin, Yu.M. Abelev, Z.G. Zubko, V. Hlushchenko, V.L. Sedin, N.I. Krieger. M. Yakovenko [3], P. Dvulit [4], as well as in the report of the State Enterprise "State Research Institute of Building Structures" [5], but these works did not summarize and critically evaluate all available data.

Therefore, the appearance of monographs by V.T. was scientifically and practically significant. Trofimov's "Genesis of the depression of loess rocks" (1999), "Theory of formation of depression of loess rocks" and others (2003), which were the result of systematization, classification and analysis of the content of hypotheses put forward by various authors about the formation of depression of loess rocks as their syngenetic or epigenetic property; generalization of the experimental data of various authors, as well as the creation of new logical-graphic models of the formation of subsidence of loess rocks of various genesis.

One of the latest studies is the dissertation work of D. Kelkai "Changes in the physical and mechanical properties of loess subsidence soils in the zone of industrial development (on the example of Cherkasy Azot OJSC)" and the work of O.V. Granko [6]. The works of these authors provide an analysis of specific factors that affect the strength of loess rocks, as well as the stability of buildings and structures. It is in these works that it is necessary to determine the influence of not individual, but a whole complex of these factors, which will make it possible to improve the quality of the assessment of the state of the natural and man-made components of the studied natural-technical systems.

The purpose of the study is to analyze the main factors affecting the deformation properties of the main structures of buildings and houses built on loess soils, to develop a classification of conditions and their operation mode according to the degree of damage to buildings.

Research materials and methods. The article uses the results of monitoring geodetic observations to study the process of emergence and development of deformations of the earth's surface and in the load-bearing structures of 273 residential buildings, as well as buildings of the Kherson State Agrarian and Economic University (hereinafter the University) (main building "Morphology", dormitory #3), which located on areas with subsidence soils.

The following research methods were used to solve the tasks: the method of monitoring the deformations of the earth's surface and the main structures of 273 residential buildings, as well as University buildings, based on the data of high-precision geodetic measurements; the cartographic method was used to build cartographic models using GIS technologies (DIGITALS software product) and mathematical processing of measurements and visualization of results. Linear and angular measurements (determination of subsidence and deformations of structures of various types); the method of mathematical modeling was used to establish the closeness of the relationships between the studied factors. Investigations of deformations of buildings were carried out using traditional methods, but in order to achieve more reliable results, various monitoring methods were combined.

Research results and their discussion. There are two types of soil conditions, depending on the amount of subsidence due to its own weight during soaking. With the first type of subsidence of the soil due to its own weight is no more 5 см. With the second type, the possible subsidence due to its own weight is greater 5 см. Soils of the second type with a layer thickness of 14-16 -m give subsidence under the weight of the building up to 50 см. Subsidence also includes dusty clayey soils, which, when soaked, give significant additional subsidence [7]. This property is characteristic mainly for loess and loess-like loams, which in an undrained state have a satisfactory load-bearing capacity due to the strength of structural connections between soil particles. When soaking, these connections are destroyed, which is accompanied by subsidence with a change in the internal structure of the soil.

Deformation of subsiding soils depends on the size and location of local sources of possible wetting of the base soils from the surface or in the event of a predicted rise in the level of groundwater within the built-up area. This deformation leads to the formation of a trough of subsidence.

The parameters of deformation of the earth's surface during soil subsidence are determined by calculation based on the data of engineering and geological investigations in accordance with Appendix 2 of the current regulatory document DBN V.1.1-5-2000.

In the calculation of subsidence and deformations of subsiding soils, the decisions adopted in design practice are used for calculating foundations and conventional schemes of soil wetting and manifestation of deformations are used.

In the regulatory document DBN V.1.1-5-2000, there are two options regarding the location of the soaking source: 1) - under the middle of the house or structure; 2) - under the end face of a building or structure (Fig. 1)

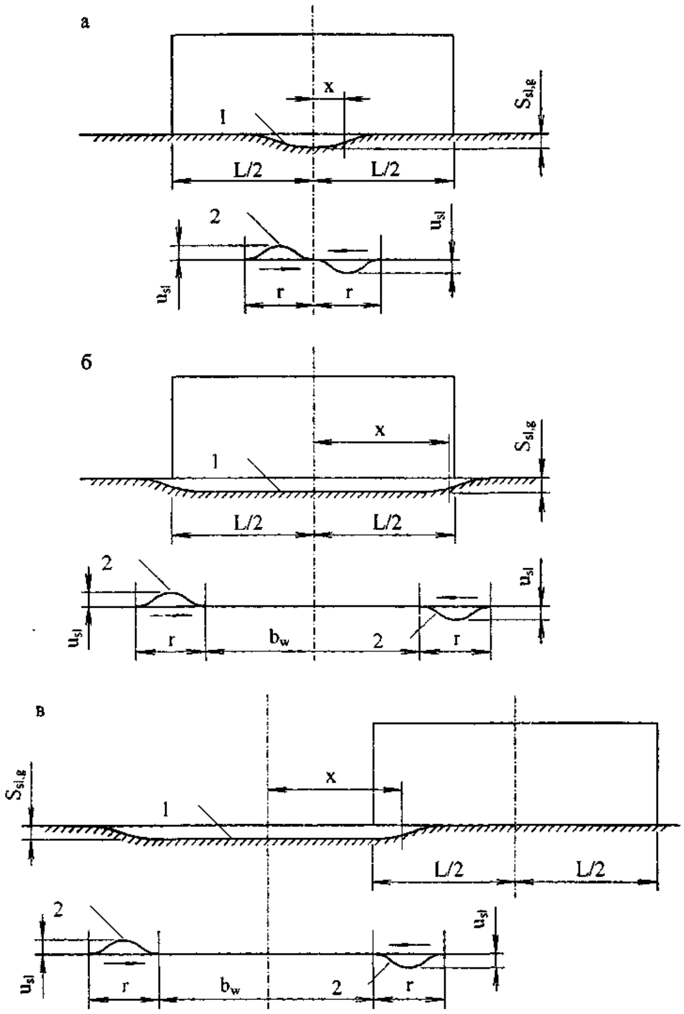

Fig. 1. Schemes of vertical and horizontal movements of the base surface during soil subsidence due to its own weight

a, b - when the watering can is located under the middle of the house; c – when placing a watering can of subsidence under the end of the house; 1 – sag funnel; 2 – horizontal movements of the surface

Effects on the structures of buildings and structures from uneven deformations of the base during subsidence of its soils as a result of soaking are taken as:

– reduction of the contact stiffness of the base on soaked areas as a result of subsidence deformations and additional deformations of non-compact soils from external loads in the upper zone of subsidence (takes into account in the complexity groups of construction conditions 1-A, 1-B, 2-A, 2-B and 2-B);

– vertical and horizontal movements of the contact surface of the base as a result of soil subsidence and additional deformations of non-settled soils due to their own weight in its lower zone on site 2 r (taken into account for construction condition complexity groups 2-A, 2-B and 2-B);

– additional loads on buried structures of buildings and structures or transformed massifs of their foundations, which arise from friction on vertical surfaces during subsidence of soils due to their own weight (taken into account in the complexity groups of construction conditions 2-A, 2-B and 2 B) [8].

The length of the section of the base, where its stiffness is reduced as a result of soil soaking, depends on the depth of foundation laying, the depth of the location of the source of soaking, the depth of the subsidence zone from the external load, and the value of the angle β to the vertical spreading of water to the sides from the soaking source, which is accepted for loess sands and loess 35°, and for loess-like loams 50°.

In groups of complexity of construction conditions 2-A, 2-B and 2-B, it is necessary to take into account, in addition to the subsidence of the soil from the external load and from the soil's own weight, as well as the horizontal movements of the earth's surface u_{sl} (Fig. 1) [8].

When conducting examinations a clear development of deformation (usually in the form of cracks) can be seen in the walls, the condition of which most fully reflects the wear and tear of buildings. In this regard, it is necessary to determine the expected damage to buildings and structures on the basis of estimated values of subsidence and deformation of subsidence soils.

$\Delta \boldsymbol{l}$ are used as a criterion for assessing the degree of deformation of the earth's surface, and the maximum opening δmax of cracks is used to assess the degree of damage in the main load-bearing structures [9].

According to the results of studies of deformations of buildings and structures, taking into account their structural features and conditions of soil subsidence, the degree of damage to objects was determined depending on the size of the opening of cracks. The analysis showed that the degree of damage depends not only on the discharge, dimensions, structural features, technical condition, nature of operation, deformations of the earth's surface of the object, but also on the location of the subsidence funnel. Buildings and structures fall into different zones of deformation of the earth's surface during forgery. In the stretching zone, deformation of positive curvature is simultaneously manifested, and in the compression zone - negative curvature [10].

It has been established that buildings without structural protection measures have almost no margin of tensile strength and a significant margin of compressive strength. Therefore, deformations of horizontal movements and positive curvature are the most dangerous for buildings. In this case, the nature of damage development in different deformation zones (stretching-compression) and the consequences are different. This is confirmed by the results of surveys of 273 buildings. Conditions: deformations of horizontal movements of stretching - from 0 to 6 10^{-3}; compressions - from 0 to 4 10^{-3}; curvature of convexity from 0 to 16· 10^{-4} $м^{-1}$, curvature of concavity from 0 to 7· 10^{-4} $м^{-1}$.

When buildings are located, the dimensions of the long side of which are 20-40 m, in different zones and when the building is affected by tensile deformations in the floor belts, less often in the walls, vertical and oblique cracks are formed, and deformations appear in several places in the long building [11]. If in the initial stage of deformation there is a uniform appearance of cracks, then from a certain moment this process slows down and then stops, the walls of buildings are divided into separate blocks and the deformation occurs due to the opening of existing cracks. This is illustrated by graphs (Fig. 2).

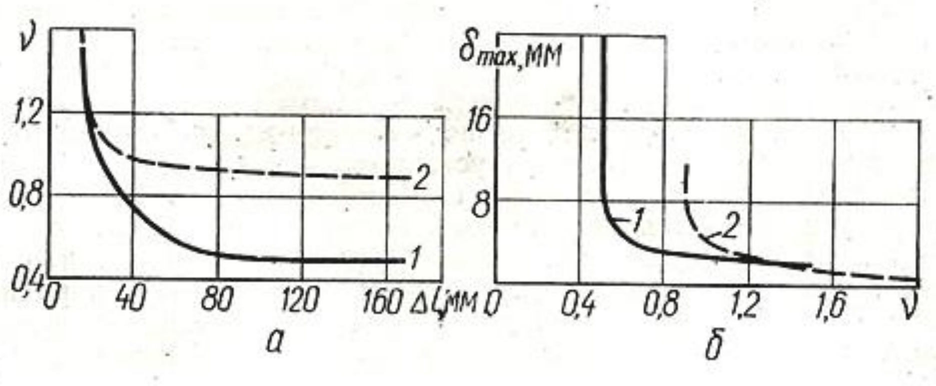

Fig. 2. Graphs of the dependence of the coefficient ν on the total deformations Δ *l* (*a*) and the maximum crack opening δ_{max}on ν (*b*)

1 – stretching zone; 2 – compression zone.

It was established that Δ *l* and δ_{max} are inversely related:

$$\nu_p=15.35\ (\Delta\ l\ ) + 0.39; \tag{1}$$

$$\delta_{\max\ p}=3.6/\nu + 0.35 \text{ at } \nu \geq 0.5, \tag{2}$$

Where ν= n_{Π}/ $n_{т}$is a coefficient characterizing the ratio of the number of openings n_{Π}on the long side of the building to the number of cracks $n_{т}$there.

The correlation ratio of dependencies (1 and 2) η_1=0.84 and η_2=0.78, respectively. At Δ *l* =0...45 mm, the number of cracks is always less than the number of slots (Fig. 1, *a* at ν≥1), and the maximum crack opening is no more than 3 mm (Fig. 1, *b*). In the interval Δ *l*= 30...100 mm, the number of cracks increases to a value that is approximately 2 times greater than the number of slots (ν=1...0.5), the opening increases from 3 to 12 mm. With further growth of deformations of the earth's surface (Δ *l > 100* mm), the number of cracks does not increase (ν= 0.5), but their opening increases (δ_T= 12 mm). There is a relationship between the values:

$$\delta_{max}= 3.7\ 10^{-4}\Delta l^2+7.3\ 10^{-2}\Delta\ l,\ \eta_3=0.93 \tag{3}$$

Thus, three stages of development of deformations of the main structures can be observed in the stretching zone:

1. with ν ≥ 1, the number of cracks can reach the number of slots, their opening is no more than 3 mm;
2. at ν = 1 ... 0.5, the number of cracks continues to grow, the speed of their opening up to δ_{max}= 10 ... 12 mm increases rapidly. At the same time, the number of cracks does not increase, and their opening increases;
3. at ν = 0.5, the number of cracks does not increase, and their opening increases.

Taking into account the above, a classification of conditions was carried out according to the degree of damage to buildings. According to the size of the maximum opening of cracks $\delta_{max}$and depending on the index of total deformations Δ *l*, coefficient ν and superficiality, damage in the stretching zone is divided into six degrees. (see table 1).

Table 1. Classification of measures by degrees of damage for different zones

Δ *l*, mm, with a storey		δ_{max}, mm	ν	Degree of damage	Damage to the walls	Measures that ensure normal operation of buildings in the event of deformations in the main structures
1–3	4–5					
Stretch zone						
0–30	0–45	0–3	1.0	I	Rare oblique and vertical cracks in the places where the partitions adjoin and in the intersections weakened by holes. 60% of cracks with opening up to 1 mm.	Carrying out cosmetic repairs after the displacement process.
30–60	45–75	3–6	1.0–0.6	II	40–50% of cracks with opening up to 1 mm. Oblique cracks in the walls. Rare cracks up to 3 mm. The capital walls depart from the partitions, gaps up to 5–8 mm.	Emergency control and installation of temporary fasteners to prevent the plaster from falling. Installation of beacons. After the displacement of the sealing of cracks in the walls, cosmetic repairs.
60–100	75–120	6–12	0.6–0.5	III	Up to 65% of vertical and oblique cracks in walls and inter-floor belts with an opening of up to 3 mm. Rare cracks of up to 4 mm between capital walls and partitions, cracks of up to 15 mm, peeling plaster.	Removal of exfoliated plaster, installation of temporary fasteners under sagging areas of ceilings and, if necessary, binding them with a metal mesh. After part-time work, repairs are carried out to restore the load-bearing capacity of the main structures.
100–150	120–180	12–18	0.5	IV	Oblique and vertical cracks under spans and in walls. 70% of the cracks have increased to 5 mm. Up to 15–20 mm vertical at the corners and at the joints of walls and partitions.	Construction of devices for volumetric crimping, installation of temporary fastening under floor slabs, temporary suspension of operation of individual premises. Carrying out restorative repairs.
150–200	180–210	18–25	0.5	V	Most (up to 70%) cracks with an opening of 5-8 mm. Cracks at the corners between capital	Additional strengthening of load-bearing structures, sealing of through cracks; temporary cessation of

					walls and at the joints of walls and partitions, vertical cracks increased to 25 mm.	operation of premises and buildings in which the main structures are broken. After additional work, repairs are carried out with filling of cracks, installation of additional fasteners, clamps, clips, etc.
>200	>210	>25	0.5	VI	Most of the cracks are 7-10 mm wide, and up to 50-60 mm at the junction with capital walls. Peeling of plaster on large areas.	It is possible to stop the operation of the building. After part-time work, strengthening of broken structures according to a special project
Compression zone						
0–40	0–60	0–3	1.4	I	Rare horizontal cracks. A network of hairline cracks is possible near the openings and in the places where the partitions adjoin.	After part-time work, cosmetic repairs are carried out
40–80	60–100	3–6	1.4–1	II	Horizontal and diagonal cracks with an opening of up to 2 mm, at joints with capital walls up to 3 mm. Swelling of plaster on the facades and in the places where the partitions adjoin.	Periodic cleaning of peeling plaster in rooms where people are constantly present. After part-time work, cosmetic repairs with subsequent filling of cracks.
80–120	100–150	6–12	1–0.9	III	Slight displacement of parts of the wall along the contact of horizontal cracks with an opening of up to 4 mm. Swelling and flaking of plaster. Cracks at the joints with capital walls with an opening of up to 5-8 mm. Distortions of slots.	Removal of peeling plaster. Temporary fastening of slots to prevent distortion, device of compensatory trenches, expansion joints. Carrying out restorative repairs after displacement.
120–180	–	12–18	0.8	IV	Slight protrusion of the walls is possible. Layering of masonry with falling out of its elements in the area of cracks with an opening of up to 5-8 mm, swelling, peeling and falling of plaster. Skew of most slots with	Introduction of additional protection measures that reduce compression, temporary sealing of through cracks, temporary cessation of operation of individual premises. Carrying out restorative repairs.

					a shift of the lower part.	

Horizontal cracks occurring mainly at the level of window and door openings are characteristic of the impact of compression deformations on the building. Note that unlike the tension zone, cracks begin to form at Δ *l*> 15 mm, ν≥1.4 and δ_{max}=2 mm (Fig. 1). With increasing compression deformations (Δ *l =30...70 mm), the number of horizontal* cracks δ_{max} increases to a value equal to the number of holes (ν=1.4...1), and the opening of cracks - up to =2...5 mm. With further growth of horizontal displacements of the earth's surface (Δ *l* >70 mm), a relative displacement of parts of the structure along the crack contact is observed.

Horizontal cracks continue to increase (δ_{max}>5 mm) and may turn into diagonal ones (ν=0.9), and their number increases slightly. Further damage occurs due to an increase in the opening of cracks when the structures are displaced along the contacts. With

$$\nu = 14.67/(\Delta l) + 0.8 \text{ at } \nu \leq 1.4; \tag{4}$$

$$\delta_{max} = 4.85/\nu - 1.52 \text{ for } \delta \leq 8 \text{ mm}. \tag{5}$$

Correlation ratio of dependencies (4 and 5), respectively η_5=0.72 and η_5=0.64.

The relationship between δ_{max} and Δ *l was established*:

$$\delta_{max} = 0.6\sqrt{\Delta l}, \ \eta_6 = 0.73 \tag{6}$$

For the compression zone, the classification of conditions according to the degree of damage was also carried out according to the same criteria as for the tension zone.

Conclusions and perspectives of research. The experience of monitoring the condition of buildings and structures allowed to develop a set of measures to preserve the normal operational properties of objects during the active stage of the process of soil subsidence and horizontal movements of the earth's surface.

The classification of measures was developed according to the degree of damage for different zones (see Table 1).

To clarify the nature of deformations in buildings and structures located in different zones of subsidence, it is necessary to continue research in other regions of the country [12]. The main measures that ensure the normal operation of buildings with detected degrees of damage are:

– carrying out a complex of observations on the condition of the main structures of buildings and timely elimination of emerging violations for I, II and III degrees of damage;

– strengthening of the main structures of objects, partial change of their mode of operation in adverse conditions (IV, V degrees of damage);

– drawing up a special project for the protection of objects that are located in particularly unfavorable conditions (VI degree of damage) in the stretching zone.

References

1. V. B. Shvets (2018) Mekhanika gruntiv. Entsyklopediia Suchasnoi Ukrainy [Mechanics of soils. Encyclopedia of Modern Ukraine] National Academy of Sciences of Ukraine, National Academy of Sciences. Institute of Encyclopedic Research of the National Academy of Sciences of Ukraine. Kyiv, Ukraine

2. Shvets V.B., Sedin V.L. (2008) K otsenke prosadochnosti lessovikh gruntov [On the assessment of subsidence of loess soils]. Poltava, Ukraine

3. Zvit za rezultatamy vibrodynamichnykh obstezhen gruntu ta konstruktsii prylehloi budivli na vul. Moskovska, 5 z metoiu kontroliu vibratsiinykh vplyviv pry vlashtuvanni shpuntovoho ohorodzhennia kotlovanu na budivelnomu maidanchyku obiektu: «Budivnytstvo zhytlovo-ofisnoho kompleksu z torhivelnymy prymishchenniamy ta parkinhom po vul. Moskovska, u Pecherskomu raioni m. Kyieva» [Report on the results of vibrodynamic surveys of the soil and structures of the adjacent building on the street. Moskovska, 5 for the purpose of controlling the vibration effects during the installation of the sheet pile fence of the pit on the construction site of the object: "Construction of a residential and office complex with commercial premises and parking on the street. Moskovska, in the Pechersk District of Kyiv"] (2020) Kyiv, Ukraine

4. M. Yakovenko (2020) Ohliad vydiv heodezychnoho monitorynhu budivel i sporud v skladnykh inzhenerno-heolohichnykh umovakh [Overview of types of geodetic monitoring of buildings and structures in complex engineering and geological conditions] Modern problems of architecture and urban planning: coll. of science works. Kyiv, Ukraine

5. P. Dvulit (2019) Determination of plumb lines with using trigonometric levelling and GNSS measurements Geodesy, cartography and aeral fotography. – https://doi.org/10.23939/istcgcap2019.01.012 (in English).

6. Granko O.V. (2008) Napruzheno-deformovanii stan trivalo navantazhenikh lesovikh osnov za umovi ïkh pidtoplennya [Stress-deformed state of long-loaded loess bases under the condition of their flooding]. Poltava, Ukraine

7. Budynky i sporudy na pidrobliuvanykh terytoriiakh i prosidaiuchykh gruntakh. Chastyna II. Budynky i sporudy na prosidaiuchykh hruntakh [Buildings and structures on reclaimed territories and subsiding soils. Part II. Buildings and structures on subsiding soils] DBN V.1.1-5-2000. (2000) Kyiv, Ukraine

8. Osnovy ta fundamenty sporud. Osnovni polozhennia proektuvannia [Bases and foundations of buildings. Basic provisions of design] DBN B.2.1-10-2009 (2009) Kyiv, Ukraine

9. Inzhenerni vyshukuvannia dlia budivnytstva [Engineering searches for construction] DBN A.2.1-1-2008. (2008) Kyiv, Ukraine

10. Grunty. Metody vymiriuvannia deformatsii osnov budynkiv i sporud [Soils. Methods of measuring deformations of foundations of buildings and structures] DSTU B V.2.1-30:2014 (2015) Kyiv, Ukraine

11. Naukovo-tekhnichnyi suprovid budivelnykh obiektiv [Scientific and technical support of construction objects] DBN V.1.2-5:2007 (2007) Kyiv, Ukraine

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АНАЛІЗ УШКОДЖЕНЬ ОБ'ЄКТІВ ВІД ВПЛИВУ ПРОСАДКОВИХ ҐРУНТІВ

У статті представлена класифікація ушкоджень об'єктів, що розташовані на просадкових ґрунтах, яка розроблена за результатами аналізу наукових вишукувань, що проводились з використанням комплексної методики геодезичних спостережень за деформаціями земної поверхні і несучих конструкцій 273 житлових будівель, а також споруд Херсонського державного аграрно-економічного університету, які розташовані на ділянках з вищевказаними властивостями ґрунтів.

Аналіз показав, що ступінь пошкоджень залежить не тільки від розряду, розмірів, конструктивних особливостей, технічного стану будівлі чи споруди, характеру експлуатації об'єкту, але і від місця розташування лійки просідання під ним.

Використання розробленої методики спостережень дає можливість в повному обсязі визначити причини і негативні фактори виникнення деформацій на земній поверхні, а також в несучих конструкціях будівель і споруд та розробити комплекс заходів зі збереження нормальної експлуатаційної якості об'єктів в період активної стадії процесу просідання ґрунтів і горизонтальних переміщень земної поверхні.

Для уточнення характеру деформацій в будівлях і спорудах, що перебувають у різних зонах лійки просідання, треба продовжити дослідження в інших регіонах країни.

Ключові слова: *деформація земної поверхні, деформація несучих конструкцій, експлуатаційні властивості, лійка просідання.*