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Dynamic activity of military transportation investigation at the construction site

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In the paper it is confirmed that any theoretical data inferior to precisely measured data due to the impossibility of considering all the factors influencing on the oscillation process. The fluctuations magnitude of a non-residential building in Poltava and the dynamic influence on the building structure and the people who can be there periodically are experimentally investigated. To evaluate the vibration impact, it is necessary to compare measured data with the permissible level of vibration in public buildings. The recommendations for the further building exploitation are based on the building structures vibration acceleration measurements results.

Keywords: vibration, building, vibration acceleration, vibration velocity, measurement.

Дослідження динамічної дії міського транспорту на будівлі

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Експериментально досліджено величини коливань нежитлової будівлі, що знаходиться в м. Полтава й оцінено їх динамічний вплив на конструкції будівлі та людей, які там періодично перебувають. Для цього проведено вимірювання вертикального віброприскорення покриття будівлі, де очікувалися найбільші значення вимірюваної величини. Для точної оцінки впливу транспортної вібрації на будівлю проведено вимірювання у різні години доби. Коливання виміряно в тій точці конструкції, де їх амплітуда найбільша, і при такому режимі джерела вібрації, при якому відбуваються найбільш інтенсивні коливання цієї конструкції. Виникнення явища резонансу виключається, так як частота вимушених коливань покриття будівлі від впливу транспорту знаходиться у між резонансній області з мінімальним перевищенням 10%. Для оцінювання впливу вібрації на будівлю необхідно порівняно виміряні дані з допустимим рівнем вібрації в громадських будівлях. Для вибору точок і напряму вібрації використовувалася наступна схема вимірів: спочатку регіструються коливання при будь-якому визначеному динамічному впливі, які забезпечують виявлення форми коливань конструкції і спектра частот коливань. Кріплення акселерометра на покриття будівлі, проводилося за допомогою магніту тобто забезпечується верхня межа робочого частотного діапазону. Для житлових і громадських будівель найбільш несприятливим зовнішнім джерелом вібрацій є рейкові транспортні магістралі: метрополітен, трамвайні лінії і залізниці. Надано рекомендації щодо подальшої експлуатації будівлі, виходячи із результатів вимірювань віброприскорення конструкцій будівлі.

Ключові слова: вібрація, будівля, віброприскорення, віброшвидкість, вимірювання.

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Introduction

It is almost impossible to prevent mechanical vibrations, which cause vibration in practice, because they exist due to production processes in the enterprises, technology of construction works and other dynamic phenomena. Equipment with dynamic loads is a source of waves permeated in the soil and affecting on buildings and structures located near the buildings, facilities with equipment and apparatuses, sensitive to vibrations, service personnel and permissible values set by normative documents rarely exceed. Even mechanical oscillations with low amplitude often cause resonance phenomena of structural elements. By the intensity of fluctuations, urban transport is the most important for a person. The vibration occurring in buildings from traffic is regularly interruptible. Technogenic dynamic loads are distributed, as a rule, to the top of the soil mass to a depth of 10-15 m. approximately to such mark the foundations of most public and residential buildings deepen.

Review of research sources and publications

V. Chernyi [7] proposes to apply a heuristic approach based on determining the probability of damage to buildings and structures with dynamic impact. The application of this approach enables to clarify the possible mechanisms of damage to the basis of the object and for certain statistics to more clearly outline the reliability degree. But it needs a rather significant and adequately representative set of injuries and accidents statistics.

The research of S. Tishchenko [4] is also based on the theory where the following assumptions have been used: the environment is regarded as completely incompressible, ignoring the change in its volume; the assumption is assumed that the dynamic action happens instantly. It has been noted that the numerical value of the specific dynamic pulse is determined by the balance of energy transferred to the environment or construction.

But V. Boyko and others [2], on the basis of calculations and experimental data, believe that in the case of inclusion of a square section objects, the maximum stresses are at angular points. That is, the assessment of the ground fluctuations and controversy should be carried out at the corners of the building. But the disadvantage of this method is the requirement for the presence of complex measuring equipment. The problems of studying the dynamic load on the design of buildings and structures are devoted to the work of V. Shvets, V. Shapovala, M. Holmyansky, A. Perelmuter, V. Karpilovsky, S. Fialko, K. Yegupova, M. Swinkin [1; 3; 5; 6; 10-12]. Recently, the market for software engineering calculations offers a lot of domestic and foreign developments, allowing a fairly reliable performance of bearing structures calculations. Unfortunately, the area of calculations related to geotechnical engineering, which is based on the processes of interaction between foundations and soils, is much less developed. Each program has both its advantages and disadvantages in terms of solving a specific problem.

Definition of unsolved aspects of the problem

But any theoretical data yields precisely measured data, due to the impossibility of considering all the factors that influence the oscillation process. So Ye. Nesmashny, V.D. Sidorenko [1] have proposed a method for multichannel oscillation measurements to determine the level of seismic soil oscillations in the building basis. At the same time, the vector module of the maximum velocity V_{max} of oscillations was determined on the three its projections basis on the coordinate axes (two horizontal V_x and V_y and one vertical V_z) in this way: based on the maximum speed value, the level of seismic oscillations was determined according to the scale in balls.

Problem statement

Problem statement is the experimental study of the non-residential building located in Poltava fluctuations magnitude and the evaluation of the dynamic effect on the building structure and the people who are periodically there; to provide guidance on available dynamic impacts on the building.

Basic material and result

Before starting building structures vibrations measuring in order to determine the dynamic state, it is necessary to obtain information constructions design scheme describing: the type, the dimensions of spans and cross-sections, nodes design of the construction elements joints, the masses of the structure and the constructions attached thereto distribution, other constructive characteristics, which affect the stiffness and mass of structures, the characteristics of the adjacent to the construction structures of equipment with dynamic loads: vibration direction, which predominate, the state of deformation by the project (anti-vibration) stitches around the perimeter of existing equipment.

Figure 1 – Device for measuring vibration parameters «Vibrometer 107V»:
1 – accelerometer; 2 – probe; 3 – vibrometer

Vibration sources in residential and public buildings are engineering and sanitary-technical equipment and industrial installations and vehicles (subway of shallow foundation, heavy trucks, railway trains, trams), which create at work large dynamic loads that cause the propagation of vibration in soils and buildings construction structures. These vibrations are also often the cause of noise in the buildings.

The permissible vibration level of these structures is determined not only by the need to ensure the structures carrying capacity with the joint action of static and dynamic loads, but also the boundaries that exclude the possibility of harmful effects on people.

In the time of evaluating the strength and structures, fluctuations reliability can be considered harmless, if for buildings walls and columns the difference between the horizontal dynamic displacements of the lower and upper ends of the column in the boundaries of the floor does not exceed 1/50000 height of the floor. In this case, the oscillations are measured at that point of the design, where their amplitude is greatest and in such a vibration mode source, where the most intense oscillations of this construction occur [9].

That is, the admissible amplitude of structures oscillations

$$A_{adm} = 1/50000\ h_f = 1/50000 \times 3.3\ m = 0.066\ mm.$$

The spectral composition of the measured oscillations is by a large excess over the background value characterized in the octave bands frequency of 31.5-63 Hz. with the distance from the amplitude source amplitude of oscillation decreases.

The influence of transport vibration on the building of the «Family World» store was explored at the address Poltava city Lenin str. 10/19 where on the road cars, freight transport, buses, trolley buses move at the distance 4 meters from the building foundation. The storehouse «World of Family» is frame one and have 4 floors. To assess the impact measurements of vertical vibration acceleration of the building coverage were made, where the highest values of the measured value were expected.

Vibrometer 107B was used for oscillation parameters measurements. Vibrometer 107B is an autonomous, microprocessor measuring device was designed to measure oscillation parameters: vibration acceleration, vibration velocity and vibrational displacement (Fig. 1). At the same time, a spectral analysis of the vibration signal is carried out. For measuring, a piezoelectric accelerometer type DN-3 was used. No. 1155. The dynamic range of measuring the mean-square values of vibration acceleration, vibration velocity and vibrational displacement is limited above the maximum value of the input signal and from the level bottom of the signal amplifier own noise and depends on the conversion factor. The limits of the relative error in measuring the signal (without considering the accelerometer accuracy) are ±5%. frequency range of spectral analysis from 10 Hz to 10 000 Hz.

The instrument sensor is directly installed on the bearing elements surface. Contribution to the vibration of building structures of several vibration sources is determined by their alternating switching off and on. The free (own) oscillations frequencies establishment is necessary in the presence of resonant phenomena (with the frequencies coincidence of the own design oscillations with forced oscillations from sources of vibration). The equipment adjacent to the construction structures during free-range measurements was completely or partially disabled.

By the place of action distinguish vibration:

a) at workplaces of enterprises industrial premises;

b) at workplaces in warehouses, dining rooms, household, duty and other industrial premises, where there are no machines producing vibration;

c) at workplaces in the premises of the plant administration, design bureaus, laboratories, educational centers, computer centers, health centers, office premises, working rooms and other premises for employees of mental labor; the total vibration in residential areas and public buildings from external sources: urban rail transport (small deposits and open subway lines, trams, railways) and motor vehicles.

Table 1 – Characteristics of oscillations effect on people, depending on the speed and acceleration of harmonic oscillations with an amplitude of no more than 1 mm

Characteristic of fluctuations effect on people	Extreme fluctuations acceleration Wmax	Extreme fluctuations velocity Vmax (mm / s)
Untangible	10	0,16
Weak tangible	40	0,64
Well tangible	125	2
Very tangible	400	6,4
Harmful with prolonged exposure	1000	16
Definitely harmful	1000	16

Sanitary norms are obligatory for all ministries, departments, enterprises, associations, organizations, institutions, regardless of departmental affiliation and ownership forms; The requirements of these norms should be considered in the normative and technical documents: standards, building codes, technical specifications, instructions, methodological instructions, etc., which regulate the design and operational requirements for vibro hazardous machinery, equipment, equipment and tools, technological processes and regulations, overseas products. Therefore, it is necessary to evaluate the effect of vibration from transport.

The following measurement scheme was used to select the points and direction of vibration: firstly, oscillations are recorded at any given dynamic effect, which ensure the detection of the structure oscillations shape and oscillation frequencies spectrum. Accelerometer attaching to building cover, was carried out using a magnet providing the upper limit of the working frequency range.

By the fluctuations intensity urban transport is most important for a person. The vibration occurring in buildings from traffic is regularly interruptible. The spectral composition of the measured oscillations is characterized by a large excess over the background value in the octave frequency bands of 31.5-63 Hz. with the removal of the oscillation amplitude decreases.

For residential and public buildings, the most unfavorable external vibrations sources are railways: metro, tram lines and railroads. Studies have shown that fluctuations with distance to a different distance from the subway are extinguished, but this process is nonmonotonic, it depends on the components in the way of the vibration propagation: the rail - the wall of the tunnel - the soil - house foundation - building structures.

As a result of the measurements first stage implementation, the points and directions of oscillations registration, which are most characteristic for this dynamic process, are revealed.

By installing the device in these characteristic points, it is obtained the dependences of the measuring parameters (amplitude, frequency, etc.) on the modes of oscillations sources. The instrument sensor is installed directly on the elements bearing surface. The equipment adjacent to the construction structures during free-range measurements was completely or partially disabled.

For accurate assessment of transport vibration impact on the building, measurements were made at different time of the day. The greatest impact is expected at rush hours from 17:00 to 18:30. At this time, public transport transports the largest number of passengers. But for comparison, vibration acceleration was measured at 10.00 – 12.00 h. Measured data are reduced to table 1. to the wall of the 3rd floor fixed cable line of tension for the trolley bus. During the trolley bus movement, there are fluctuations of the 3rd floor wall, so it is necessary to check by means of measurements whether they enable vibration accelerations in the vertical and horizontal directions. Data is listed in Table 1.

To evaluate the impact of vibration, it is necessary to compare measured data with the permissible level of vibration in public buildings. The permissible level of vibration in public buildings is a factor that does not cause significant people embarrassment and significant changes in the functional state of systems and analyzers sensible to vibrational influences. According to [9], under the action of a constant local and general vibration, the normalized parameter is the vibration velocity mean-square value (V) and vibration acceleration (a) or their logarithmic levels in decibel.

The frequency range prevailing on the 3rd floor and covering the building according to the measured measurements from 17.7 to 45.95 Hz. according to Table 2, it is set the permissible values of vibration acceleration at the appropriate frequency, which are presented in Table 1.

According to [8, 9], in the requirements absence for limiting the amplitudes of oscillations associated with the placement of precision equipment or the systematic presence of service personnel, the permissible amplitudes of vertical fluctuations of the coating structures are determined by the carrying capacity and the maximum allowable dynamic deflection of the structure. The amplitudes of oscillation in mm, corresponding to the maximum allowable dynamic deflection of the structure, are determined depending on the frequency of forced oscillations by the formula.

Table 2 – The values of the building measured vertical vibrations

Frequency Hz	Average vibration acceleration m/s^2	Limit-permissible vibration acceleration m/s^2	Mark	Notes
Vibration coverage at 17.00-17.30				
49,95	0,0159	0,093	3	Vibration acceleration in the vertical direction
49,95	0,01980	0,093	3	
49,95	0,020	0,093	3	
49,95	0,01847	0,093	3	
49,95	0,01947	0,093	3	
49,95	0,01972	0,093	3	
Vibration on the 3rd floor at 17.00-17.30				
41,7	0,00671	0,038	2	Vibration acceleration in the vertical direction
41,7	0,00528	0,038	2	
45,95	0,00745	0,093	2	
45,95	0,00714	0,093	2	
45,95	0,00687	0,093	2	
44,01	0,03164	0,048	3	Vibration acceleration in the horizontal direction

Table 3 – Acceptable values of vibration in the administrative buildings and in public buildings according to [9]

Middle geometric frequency of bands, Hz	Vibration acceleration m/s^2
16	0,0019
32	0,012
63	0,42

For frequencies of oscillations from 10 to 100 Hz (in this range are the frequencies of forced fluctuations of coverage from traffic)

$$A_0 = \frac{1}{n_0}, \quad (1)$$

where n_0 – the frequency of forced oscillations, Hz.

Acceptable amplitudes (vibrational displacement) calculated by the above formula for the coating are presented in Table 1.

According to the normative documents, the amplitude structures forced oscillations at the same amplitude of the active force and at other equal conditions depends on the frequency ratio of forced oscillations to the structure of own oscillations frequency. At the frequencies coincide, the phenomenon of resonance occurs in a number of cases, the amplitudes of oscillations increase sharply. Therefore, it is necessary to investigate the possibility of resonance. The own frequency of the store building «The world of the family» by the street. Lenin 10/19 is calculated. It is determine the own oscillations frequency according to the empirical formula

$$\lambda = \frac{1}{T} = \frac{1}{0{,}0905\mu\sqrt{b}}\ \text{, Hz ,} \qquad (2)$$

$$\mu = \frac{H}{b} = \frac{14.2}{208.12} = 0.068\ , \qquad (3)$$

where H – height of the building, m. Fluctuations have been measured on the roof of a 4 storey building, so it accepted the building height – 14,2 m; b – the size of the building in plan, m^2.

$$\lambda = \frac{1}{0.0905 \cdot 0.068 \cdot \sqrt{208.12}} = 11.24\ \text{Hz.} \qquad (4)$$

So, the frequency of forced fluctuations of the building 3rd floor is 41,7 – 45,95 Hz, the excess of the forced oscillations frequency over it's own frequency is $\frac{41.7 - 11.02}{41.07} \cdot 100\% = 75\%$ The phenomenon of resonance does not occur.

According to the normative documents [9], the coating designs have a number of their own oscillations frequencies, which sequence is arranged in order of growth, called the spectrum. To each frequency spectrum corresponds its own form of oscillation. At calculating, there is no need to calculate the full spectrum of the own oscillations frequencies, but it can be limited to a reduced spectrum, by calculating several necessary frequencies of the spectrum. The number of the reduced spectrum of the coating structures own oscillations frequencies is determined depending on the forced oscillations source frequency so that the last from the calculated frequencies of the reduced spectrum are higher than the forced oscillations source frequency. Loads without mass (wind, inertial) in determining the frequencies and internal oscillations forms to the calculation are not accepted. To cover the frequency of their own vertical vibrations are determined by the formula:

$$n_s = 0.159\varphi_s^2 \sqrt{\frac{EI}{ml^4}}\ , \qquad (5)$$

where n_s – internal oscillations frequency per s tone in Hz;

φ_s – frequency coefficient, on the type of construction depending;

E – module of longitudinal material elasticity, kg / sm^2;

I – the cross section inertia moment, cm^4; coating thickness ≈ 60 cm;

$$I = \frac{60 \cdot 860^3}{12} + \frac{60 \cdot 480^3}{12} = 37.32 \cdot 10^8$$

m – weight of coverage length unit, kg;

$m = 1 \cdot 0.6 \cdot 2400 = 1440$ kg.

l – estimated coverage length, m.

The own oscillations frequency of 7 tone:

$$n_7 = 0.159\varphi_s^2 \sqrt{\frac{EI}{ml^4}} =$$

$$= 0.159 \cdot (7 \cdot 3.14)^2 \sqrt{\frac{20 \cdot 10^4 \cdot 37.32 \cdot 10^8}{1440 \cdot 1340^4}} = 30.73$$

The own oscillations frequency of 8 tone:

$$n_8 = 0.159 \cdot (8 \cdot 3.14)^2 \sqrt{\frac{20 \cdot 10^4 \cdot 37.32 \cdot 10^8}{1440 \cdot 1340^4}} = 40.13$$

The own oscillations frequency of 9 tone:

$$n_9 = 0.159 \cdot (9 \cdot 3.14)^2 \sqrt{\frac{20 \cdot 10^4 \cdot 37.32 \cdot 10^8}{1440 \cdot 1340^4}} = 50.79$$

The calculation error of own oscillations frequencies due to materials properties changes, deviations from the calculation scheme from the actual modes of structure operation is considered by own oscillation frequencies ε error coefficient the by the formula

$$n_s^{/} = (1 + \varepsilon) n_s\ \text{Hz.} \qquad (6)$$

The own oscillations frequency of 7 tone:

$n_7^{/} = (1 + 0.15)30.73 = 35.33$ Hz.

The own oscillations frequency of 8 tone:

$n_8^{/} = (1 + 0.15)40.13 = 46.14$ Hz.

The own oscillations frequency of 9 tone:

$n_9^{/} = (1 + 0.15)50.79 = 58.41$ Hz.

As the frequency of forced fluctuations building coverage from the transport impact is from 49.95 Hz and 41.07 Hz, which is in the interresonance region. The forced oscillations excess over it's own frequency of 8 tone: $\frac{49.95 - 46.14}{49.95} \cdot 100\% = 10\%$. The forced oscillations excess over it's own frequency of 9 tone: $\frac{41.07 - 35.33}{41.07} \cdot 100\% = 14\%$. The resonance phenomenon does not occur.

Conclusions

Comparing the measured mean-square values of vibration acceleration and on the 3rd floor of the store «World of the Family» at Lenin str. 10/19 with the maximum permissible values, it is concluded that the measured mean-square values of vibration acceleration do not exceed the maximum-permissible values. The resonance phenomenon emergence is excluded, as the transport impact building coverage frequency is between the resonant area with a minimum excess in 10%. Further building exploitation at such values of dynamic loads is possible.

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