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Ministry of Regional Development and
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International Conference

Seismics-2014

„ Seismic resistance and rehabilitation of buildings“

Transactions

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Tbilisi, Georgia

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ESTIMATION METRO INFLUENCE ON STRUCTURES ADJACENT BUILDINGS

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Abstract: The article is considered the impact of the dynamic vibration load of Metro on bearing capacity structures of nearby buildings. The goal of theoretical research is to establish the effect of the dynamic loads of Metro on the stressed state of bearing structures of buildings.

Key words: computer modeling, life cycle, vibration loads, structural engineering, information technology, strain

Urgency of the subject.

Often, due to lack of available space in the big cities the construction of residential and public buildings makes near the subway lines. The growth of all types of traffic flows, increasing of the speed and intensity of traffic make the necessity for obtaining the quality and quantity of estimates of the influence of transport vibration. Both in domestic and foreign literature appear periodically reports about negative effects of transport vibration, but it is usually not taken into account either in new construction or renovations in existing buildings and structures. The fact that the transport vibration does not lead to emergency situations and explains the practical absence of regulations governing its intensity in numerical estimates of the criteria of durability and reliability of objects. The questions of ensure the reliability of structures related to transport vibration, may soon become relevant, taking into account the total physical deterioration of existing buildings, especially monuments that will not demolished with the modernization of the historical center.

Direct application of traditional theoretical methods of solution of dynamic problems and methods of classical structural mechanics do not provide sustainable solutions that are suitable for practical use.

Numerical modeling of the impact on the complex building structures of random waves of a different nature is the actual problem for reliability and safety of construction projects during the operational phase. Vibration created by subway train is the most intense and tangible for human. And the vibration is usually aggravated by the lower to the upper floors.

Area of research.

Foreign scholars pay great attention to the problem of construction nearby subway. Konstantinos Vogiatzis works [3] are dedicated to this problem. Scientists which examine the problems of subway influence, mainly investigate dynamic loads influence on soil and underground structures. In number of works of researchers C.O. Aksoy, T. Onargan [5], Mete Kun (Turkey) [7], Jiangfeng Liu, S. Imanzadeh (France), Taiyue Qi, Zhanrui Wu (China) [6], Mohammad S. Pakbaz, K.H. Bagherinia (Iran) [8] are proposed computer modeling variants of enclosed structures and underground installations for subway construction in different program complexes. Also different measures are proposed for decreasing destructive influence on soil at tunnels construction. All these works are dedicated to investigation of stress-strain state of underground structures and soil at subway construction. In Aijun YAO, Xuejia YANG, Lei DONG (China) [9] works is considered the variant of foundation protection from pernicious influence of subway lines, in particular from vibrations.

The scientists' minority pay attention to stress-strain state of bearing structures and foundations of ready-built buildings nearby subway lines. In Paul Simon Dimmock (Australia), Robert James Mair (UK) article [4] is carried out such investigation and performed the bearing structures analysis for low-rise buildings

Currently in traditional dynamics of building structures adopted the concept the natural oscillation frequencies of of building elements for matching lead to resonance phenomena. I would like to underline that this is not the resonance phenomena, and not even an error in the design and construction – just the building is designed based on the classical principles of structural mechanics, as the result, system can be at the critical stability.

One of the main tasks of the solution of this problem is the task of developing methods for the numerical simulation of the effects of vibration on buildings and structures that are close to the subway. In connection with the above, the task of assessing the safety of buildings, located near the traffic flow, it seems that an urgent task for the economy.

The Solution.

Reinforced concrete monolithic structure are more resistant to vibration under dynamic effects. Compared with buildings made of prefabricated concrete elements, they reduce vibration level of overlaps by 5-8 dB [2]. Such abatement is specified by peculiarities of dynamic work of monolithic structures, which doesn't sustain resonance, but "softer" resonant phenomena. The most appropriate scheme of the building in this case is a column framework whose efficiency increases with increasing of thickness of the slabs and the reducing of column section. In the capacity of foundation is always recommended to use a solid monolithic concrete slab, which smooths the effect of inhomogeneities of subgrade and promotes the distribution of oscillations along the basement area and therefore, their reduction. Civic monolithic buildings can be located even in the immediate vicinity of the subway tunnels.

Creation of computer models is appropriate of big sense, that adequately describe the operation support systems of buildings under dynamic loads influence caused by subway.

The methods used.

Abstract computer model of the building is designed to study the behavior of the load-bearing elements of the building. It is located in 10 meters from the subway tunnel with shallow foundation slab and soil model, which simulated the movement of subway. Computer modeling was performed with the help of of LIRA SAPR software system. Numerical simulation example in this article allows multiple times and in a wide range of variable input parameters and conditions for the functioning of a complex system «aboveground part of the building - ground - soil - subway», replacing, thereby, experimental investigations of computational experiment. Such realization leads to a time-saving solution of a number of similar problems, and and allows draw corresponding conclusions on the stress-strained state of load-bearing elements, exposed to permanent effects of dynamic loads. By the author of this article conducted research of frame-monolithic building. The problem was solved in two-dimensional statement. In computation columns modeled by plates, girders modeled by rods with rigid joints, overlaps-rods with reduced stiffness, the soil was modeled by plates of variable stiffness.

System DYNAMICS + [1] is used in the program complex LIRA-SAPR considering the peculiarities of behavior of load-bearing elements under the influence of dynamic loads. The algorithm is based on dynamic loads put an iterative process, alternating phase set of static load on the structure, later setting the weights of the masses, later the task of dynamic loading on the structure. For modeling of dynamic loads of subway motion used sinusoidal load.

Given in the form $A\sin(\omega \cdot t + \varphi)$, (1)

where A – amplitude, ω – frequency, φ – phase shifting, set the beginning and finishing of load action;

In the corresponding entry field – amplitude P impact forces, frequency of influence in radians, phase shifting in degrees, as well as the beginning and finishing of exposure in seconds. Reflection of diagram z(i)=P*sin(ti) performed with the command of viewing.

To solve the problem of dynamic analysis of structures using two main methods:

- direct integration of the equations of motion;
- decomposition by own forms.

Method of decomposition by own forms can be applied only in the linear calculation, since the principle of superposition is not valid in the nonlinear theory. Direct integration methods are general and can be applied to solve all the problems of the dynamic analysis of structures.

In the dynamics in time used the direct integration of the equations of motion. The term "direct" means that the integration is not performed before any manipulation of equations [1].

The calculation is based on the dynamic impact on the solution of differential equations

$$M\ddot{\vec{u}}(t)+C\dot{\vec{u}}(t)+K\vec{u}(t)=\vec{q}(t), \qquad (2)$$

where M, C, K – correspondingly matrixes of mass, damping and rigidity of system,

$\vec{u}(t)$, $\dot{\vec{u}}(t)$, $\ddot{\vec{u}}(t)$ – vectors of nodal displacements, velocity acceleration in time moment t,

$\vec{q}(t)$ – loading, correspond to time moment t.

It is considered that the initial velocities are zero $\dot{\vec{u}}(0)=0$, and the initial movements are derived from decisions of the first loading $\vec{u}(0)=\vec{u}_1$.

From the system (1) of ordinary differential equations with constant coefficients follows, that approximate the velocity, acceleration and displacement can be any finite-difference expressions of the displacement. For accelerations at the time moment t, using of central difference method, we can write:

$$\ddot{\vec{u}}(t)=\frac{\vec{u}(t+\Delta t)-2\vec{u}(t)+\vec{u}(t-\Delta t)}{\Delta t^2} \qquad (3)$$

Mistake in calculation by the formula (2) is in order Δt^2, and to calculate the velocity and displacement with errors of the same order necessary to use next expression

$$\dot{\vec{u}}(t)=\frac{\vec{u}(t+\Delta t)-\vec{u}(t-\Delta t)}{2\Delta t}, \qquad (4)$$

$$\vec{u}(t)=\frac{\vec{u}(t+\Delta t)+\vec{u}(t-\Delta t)}{2} \qquad (5)$$

Substituting the expressions (2), (3) and (4) to expression (1) and determining the vector $(\bar{u}(t+\Delta t)+\bar{u}(t-\Delta t))$, receive the following system of equations:

$$\left[\frac{2M}{\Delta t^2}+\frac{C}{\Delta t}+K\right](\bar{u}(t+\Delta t)+\bar{u}(t-\Delta t))=2\left(q(t)+\frac{2M}{\Delta t^2}\bar{u}(t)+\frac{C}{\Delta t}\bar{u}(t-\Delta t)\right) \quad (6)$$

"New" displacements $\bar{u}(t+\Delta t)$ are determined by the are determined by the previously found displacements $\bar{u}(t)$ and $\bar{u}(t-\Delta t)$ by solving the system of equations (5). Such integration scheme called the implicit integration schemes. Such integration scheme is called the modified method of central differences. Expression (5) is the source for the decision of both linear and nonlinear problems of by direct dynamic calculation in software package LIRA-SAPR.

Solving the problem (1) consistent mass matrix is used, based on the same approximate the functions that was based the rigidity matrix. In this approach takes into account the rotational inertia - "torsion" elements of the mass are appeared.

In integrating the equations of motion in the PROCESSOR window displayed the kinetic energy diagram ($\frac{1}{2}\dot{u}_t^T M\dot{u}_t$), which allows you to estimate the nature of the integral transmission process. If further integration is not interest, it is possible to interrupt the process of integration, and browse the results to the point of interruption.

Vibration influence of subway on the stress-strain state of bearing structures of a buildings.

There are a large number of publications, authors of which have different approaches to the calculation of buildings and structures. However, not every method can reflect the real work of the support system of the building. Most of these methods involves the definition of the stress-strain state of load-bearing elements, based on the final design scheme of the building, fully loaded. Part of methods are focused on the characterization only separate parts of the building, which also leads to a distortion of the real work of the building. Therefore requires their further development and refinement. The purpose of the theoretical and experimental researches of many scientists now is to determine the contribution of the vibrations on stress-strain state elements supporting systems of buildings.

Neither in Ukraine nor in the CIS or in Euronorm no existing rules regulating allowable vibration levels for buildings and structures, caused by traffic. Vibration from the subway is evaluated by sanitary and hygienic requirements. You can see СП 23-105-2004 «Evaluation of vibration in the design, construction and operation of underground». But this document describes some methods of assessment vibration impact according to the sanitary norms of vibration impact on people at night and day time. However, in the normative documentation not specified methods for evaluating the impact of a permanent dynamic loads on the bearing capacity of building structures, and the possibility of crack formation. In this case, a very important factor is the possibility of resonance vibrations in the building caused by external dynamic vibration of subway.

Investigation of own frequencies of building structures has great practical value in solving various dynamics problems, analysis of vibration propagation pathway of buildings is a complex engineering task, that can not be solved only by means of experimental or theoretical methods.

Depending on the design of solutions, efficiency and safety, as well as other conditions apply different methods of numerical modeling of vibration loads effect on multistory buildings. In all cases, modeling process is contained that the building is presented as system «aboveground part – ground – soil». At modeling must taking into account the properties of the soil, type of foundation, the type of structural scheme (arrangement of columns and stiffening diaphragm, stiffness of structural elements, the thickness of slabs, of reinforcement methods, the type and grade of concrete of the main load-bearing structures).

Soil condition has the greatest influence on the bearing capacity of the building under the influence of constant dynamic load. Under constantly acting vibrations the soil may settle, change its strength characteristics, it may be lowering of groundwater level, and in combination with constant vibration loads, such a state can lead to cracking in structural elements.

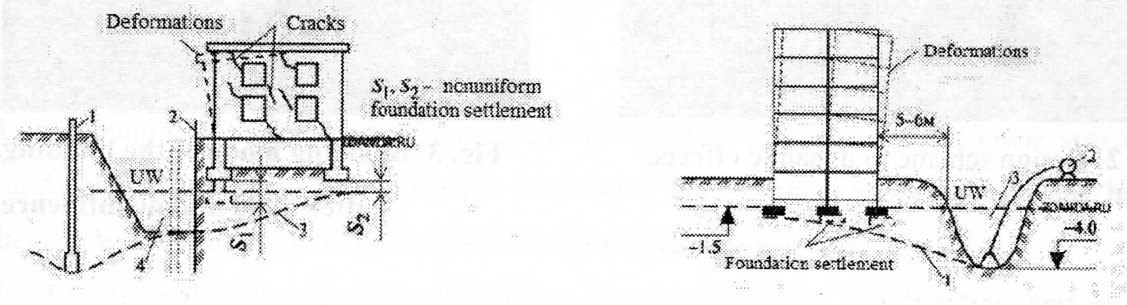
Also of great importance has age of the building, located in zone of vibration influence. For example, the impact of vibration on the newly constructed building can be completely negligible on the strength characteristics of structural elements. In this case if vibration is within sanitary norms, therefore vibration on structure of the building has almost no effect.

If the building has more than thirty years of service, may develop deformities due to various reasons, such as the natural aging of the material, soil settlement, fatigue damage, etc. (fig.1, a, b). In these cases, the vibration loads of shallow subway can play a decisive role under aggravation of building deformation, even lead to a breach of its reliability and safety.

In fig. 2, 3 an example of a computer modeling of dynamic effects of subway on the building under construction.

Abstract computer model of the building is designed to study the behavior of the load-bearing elements of the building. It is located in 10 meters from the subway tunnel with shallow foundation slab and soil model, which simulated the movement of subway. Because the length of subway train is 140 meters that exceeds the length of the ordinary dwelling house or the length of the thermal block, numerical experiments consider only the two-dimensional problem.

During the motion of subway trains, there are several sources of vibrations. There are the engine work , work of compressor, brake system of the train [3]. Oscillations with a frequency of 35-50 Hz caused by vertical oscillations of unsprung mass of trains. Wheel pair can be viewed as a system with one degree of freedom, elasticity is the elasticity of the rail base. The own frequency of the system - 40 Hz. Oscillations with a frequency of 50-60 Hz appear due to the action of horizontal vibration. Movement of subway trains causes vibrations of building constructions with a frequency of 35-60 Hz and an amplitude of a micron to 1-3 mkm. Horizontal vibrations are predominant. Vertical oscillations have the same frequency content of two or three times smaller amplitude. The largest amplitudes of horizontal vibrations are observed in the level of the basement floor of the building. Here the amplitude of the walls of 2-2.5 times more than the amplitude of the first floor of staircase. Above the first floor vibration amplitude can be changed in the direction of decreasing, and in the direction of increasing.



a) b)

Fig.1, a, b. Deformation of the building under changes in the properties of soil

The primary cause of the oscillations is the contact interaction of the rolling stock wheels and rails. The main cause of the vibration excitation wheel-rail system is the presence of joints the way that leads to jump in at the turn of the wheel and uneven load in the transition from one wheel to the next rail link.

Computer modeling performed with application of the program complex LIRA-SAPR by method of integrating the dynamic loads. Presented in this work the numerical experiment repeatedly and in a wide range of variable input parameters and operating conditions of a complex system «aboveground part of the building - ground - soil - subway», replacing, thereby, experimental investigations of computational experiment. In the software package calculation was performed using the subsystem DYNAMICS +. Was set vertical dynamic load along the Z axis with the amplitude of oscillations ω=35 radian, corresponding f=50 Hz, amount of taken into account waveforms – 100. Calculations are made with the integration step 0,1 c, integration time – 30 s.

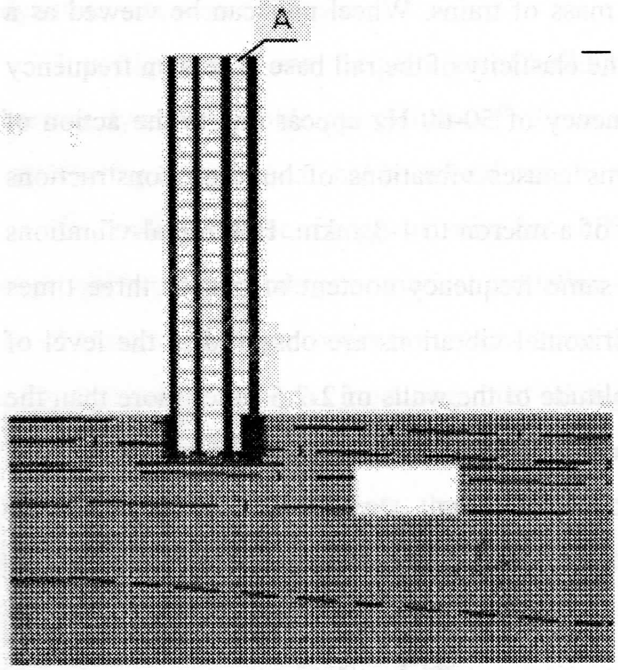


Fig. 2. Design scheme to dynamic effects;

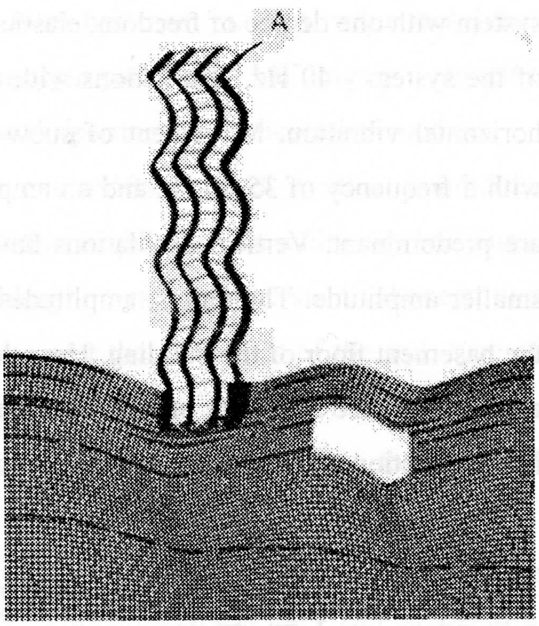


Fig. 3. Buckling mode of the building, after the dynamic influence

Figure 3 shows the form at t =16 c.

Figure 4, a and b are graphs of acceleration at the reference point A.

Table 1 gives a comparative analysis of the permissible vibration acceleration according to sanitary norms, standard ISO, and received results in the numerical experiment.

During researches was established:

- Additional precipitation bases depending on the types of soil, their condition and the vibration intensity reaches *50–200 мм, is usually uneven, and their development is comparable with the* period of operation of the facility;
- Projects newly constructed within the existing transport vibrations of buildings and structures shall be made according to the damping properties of the soil of their bases to meet design loads and impact of transport modes;

- Should be noted practical absence of standards of acceptable levels of vibration of the soil and buildings caused by traffic. Navigate in this case on the sanitary standards should be very careful, As for human and building structures vibration in different frequency ranges have different degrees of dange. Equally, very problematic spreading of earthquake engineering on the transport vibration standards, are themselves in some cases are quite problematic.

Table. 1 Permissible root mean square deviation of acceleration along the axis Z

Designation of the normative document	u·10^{-3} , м/s^{2}in octave bands with geometric mean frequency, Hz	
	31,5	56
CH2.2.4/2.1.8.566	7,0	12,75
ISO 2631-2	27,6	49,06
The experimental results	66,25	138,62

Conclusions.

1. A large number of experimental studies of the vibration influence on the lower structures of buildings and structures allows the use of existing mathematical models, and using based on them software systems, to conduct a series of numerical experiments.

To determine the stress-strain state of the support system of the building and ensure its information support throughout the life cycle of the information necessary to create a model of the construction, which should be based on mathematical models that adequately reflect the spatial work bearing system at each stage of the life cycle. Unified information model allows: efficiently react to emergency situations; model the processes of development of certain of negative processes; evaluate the stress-strain state at any stage of the life cycle of building object.

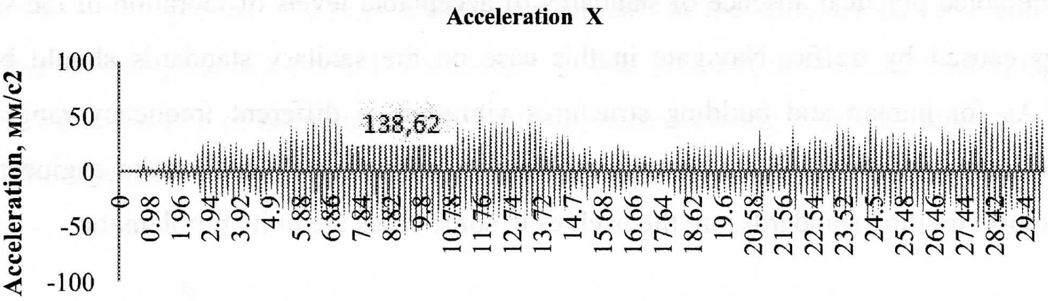


Fig. 4,a - acceleration along the X-axis at point A

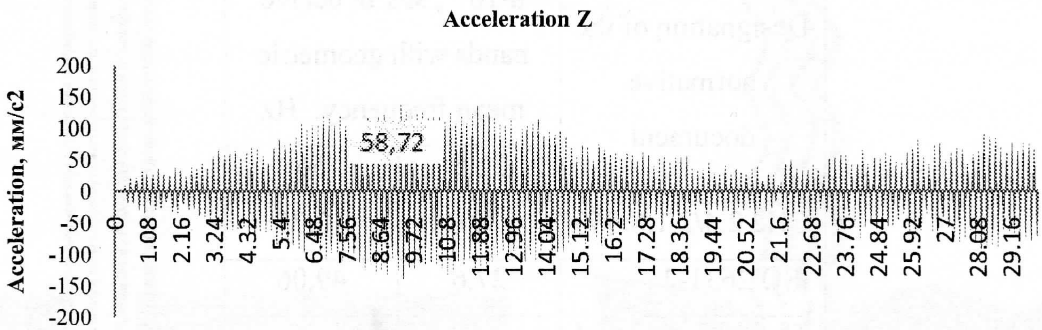


Fig. 4, b - acceleration along the Z-axis at point A

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