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Estimation of Seismic Resistance of Buildings by the Dynamic-geophysical Method, Taking into Account the Peculiarity of the Interaction of the Seismic Wave with the "Ground-Building" System

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Abstract: Since modern even numerical packages do not allow to fully provide an equivalent model for modeling existing structures taking into account the ground massif, its relief and surrounding objects, the proposed experimental-calculation method allows to create a design scheme of the system directly on the site.

Keywords: Earthquakes, Seismic, Seismic wave.

I. Introduction

"Ground-Building" System

In this article given results of scientific researches provided by usage of a method of dynamic-geophysical tests in zones of catastrophic earthquakes. In the course of the research, there were characteristic features of the destructive effect of seismic waves on buildings and structures, depending on the nature of the terrain, ground conditions, structural design, geometry of buildings and structures.

Existing approaches to measure seismic resistance of buildings and structures are built on an oscillatory quasi-static approach and, at best allow to take into account seismic effects through accelerograms. However, taking into account all the features of the ground, relief and surrounding objects, reliable selection of accelerograms is practically impossible. Existing approaches to measure seismic resistance of buildings and structures are built on an oscillatory quasi-static approach and, at best allow taking into account seismic effects through. While practical data show that the destruction of buildings from seismic action depends on ground conditions, terrain topography, seismic wave directions, geometry and structural solutions of structures, peculiarities of the location of stiffening cores in the form of lift shafts and stair flights. If we try to take into account the influence of all these factors on existing structures and soils, then this can really be done only for existing objects by analyzing the nature of seismic waves passing through the "ground-building" system using a multichannel measuring system. Thus, in the opinion of the authors, registering with the help of a multichannel measuring system the passage of seismic waves can be seen through the ground and the structure, one can also see the features of the passage of waves through the system" ground-building system" and the resulting features of the system's reaction to the dynamic effect. Since modern even numerical packages do not allow to fully provide an equivalent model for modeling existing structures taking into account the ground massif, its relief and surrounding objects, the proposed experimental-calculation method allows to create a design scheme of the system directly on the site. Such a design scheme equipped with a multichannel measuring system with sensors installed both on the ground and on the building itself makes it possible to see the interaction of seismic waves with the "ground-building" system. Thus, a multichannel measuring system is created directly on the site, the seismic resistance of which

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must be checked [1-5]. To record the dynamic impact, three-component accelerometers are used, which are installed according to a certain rule, accelerometers are installed on the ground, inside the building and on its floors. The dynamic influence on the "soil-construction" system is registered from micro seismic waves or pulses from machines such as "Geoton" or it can be registered from the passage of trucks or other sources of seismic impulse, and the location of the source of dynamic impact can be changed to identify the necessary options for interaction of seismic waves with the "ground-building"system or boundaries where lesions can occur can be detected.

Research Earthquake in Nepal

Table 1. Mobile diagnostic complex "Struna".

Building No.	The predominant period of natural oscillations along the X axis, seconds	The predominant period of natural oscillations along the Y axis, seconds	Conclusion About the category of building condition and it's seismic resistance	Resistance in points	Recommendations
1	0.64	0.71	Building depreciation on the X axis **, 16%. Building depreciation on the Y axis, 0%. Ultimate acceleration along the X axis, which can withstand the building Ax = 1.36 m/s^2. Ultimate acceleration along the Y axis, which can withstand the building Ay = 1.1 m/s^2; Seismic resistance is 7.5-8 points.	1.5	1. Seismic reinforcement is required. 2. A repeated dynamic-geophysical test of the building is required. 3. The process of latent cracking in the structures has not been completed (high-frequency noise is observed) it is recommended to install an automatic monitoring system for earthquake resistance of the building
2	1	1	Building depreciation on the X axis ***, 27%. Building depreciation on the Y axis , 81%. Ultimate acceleration along the X axis, which can withstand the building Ax =0.56 m/s^2 Ultimate acceleration along the Y axis, which can withstand the building Ay =0.56 m/s^2; Seismic resistance is 6.5-7.0 points.	2.5	Urgent seismic reinforcement or demolition of the building is required

Let us consider some examples illustrating the effectiveness of such full-scale experimental studies. With the earthquake in Nepal in 2015, we had to assess the seismic resistance of two identical multi-storey buildings "Media-TV center" in Kathmandu. The buildings are multi-storey, the bearing part is made of a monolithic reinforced concrete

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frame filled with hollow brick. The following designations have been adopted: X-long side (for building No. 1, for building No. 2-short side); Y is a short side (for building No. 1, for building No. 2 is a long side) and Z is the height. Building number 1 was located closer to the epicenter and the length of the side is oriented perpendicular to the movement of the wave. Building number 2 long side coincides with the direction of motion of the wave [6-8]. The results of the diagnostics of the buildings after the seismic impact showed that building No. 2 suffered more, it received emergency damage in the form of broken columns at the level of the top of the 2nd floor (from the ground level), see Figs. 1-8. The results of dynamic tests of two buildings of the TV center using the mobile diagnostic complex "Struna" are given in Table 1.

* - For dynamic-geophysical tests a specialized mobile diagnostic complex "Struna" was used; ** - building 1 axis X (accelerometers) is directed along the long side, the Y axis (accelerometers) along the short side; *** - building 2 axis X (accelerometers) is directed along the short side, the Y axis (accelerometers) along the long side. Scientific adviser: Candidate of Technical Sciences, Associate Professor G. M. Nigmetov. Responsible engineer A. S. Maklakov.

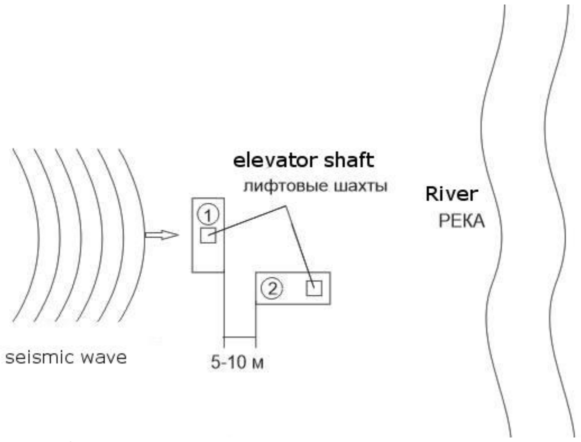

Fig. 1. Scheme of the impact of the seismic wave front on Building 1 and Building No. 2 Media-TV center "Kantepur" in Kathmandu in the Republic of Nepal of one constructive execution in the catastrophic earthquake in April 2015.

Fig. 2. Heavy damage to the top of the reinforced concrete columns at the level of the 2nd floor of Building No. 2 Media-TV center "Kantepur" in Kathmandu in the Republic of Nepal in the catastrophic earthquake in April2015, Building No.1was slightly damaged.

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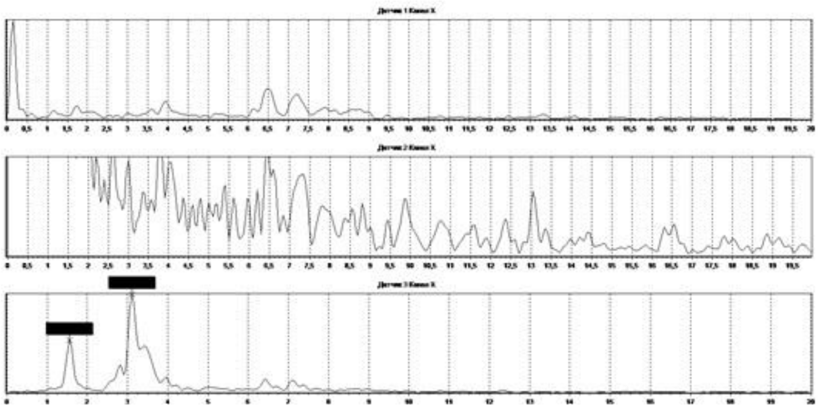

Fig. 3. The spectrum of the natural oscillations of Building 1 along the X axis.

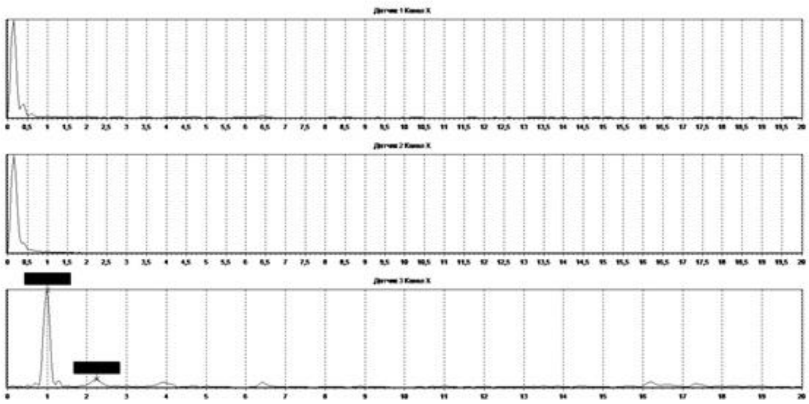

Fig. 4. The spectrum of the natural oscillations of building No. 2 along the Xaxis.

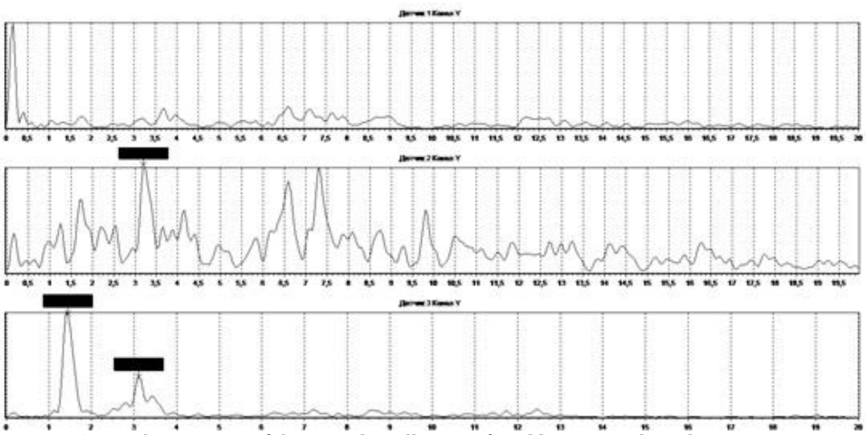

Fig. 5. The spectrum of the natural oscillations of Building No. 1 along the Y axis.

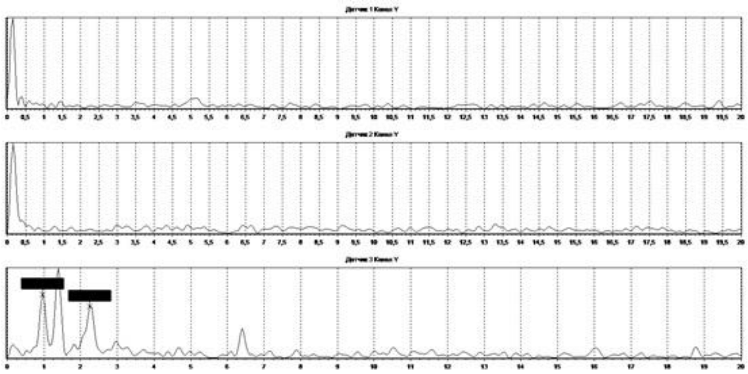

Fig. 6. The spectrum of the natural oscillations of building No. 2 along the Y axis.

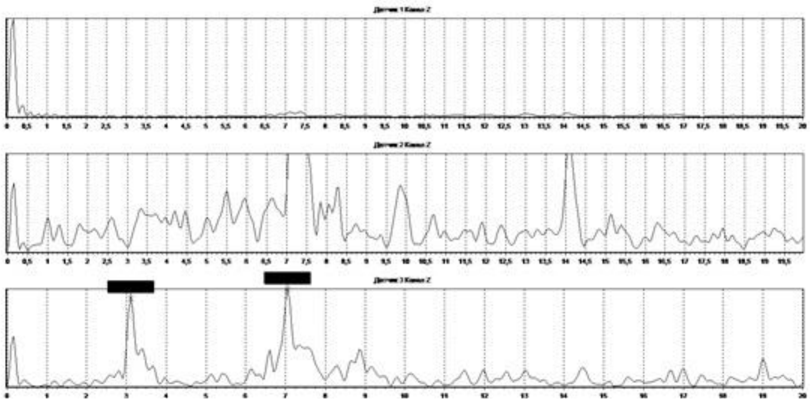

Fig. 7. The spectrum of the natural oscillations of building No. 1 along the Z axis.

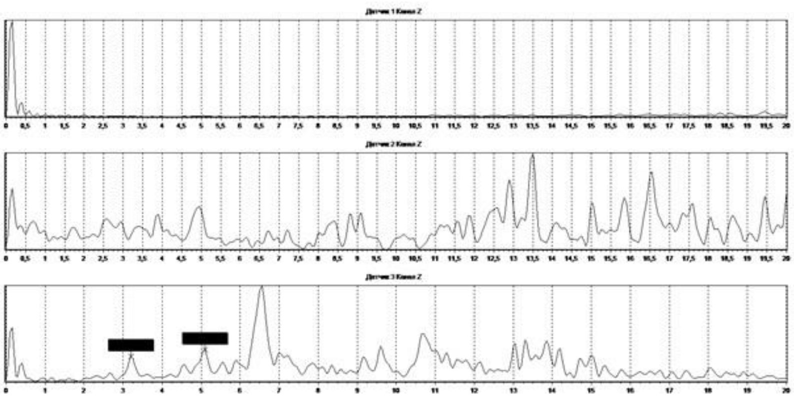

Fig. 8. The spectrum of the natural oscillations of building No. 2 along the Z axis.

The considered case of seismic action on reinforced concrete monolithic frame buildings shows that the seismic wave is more dangerous when it coincides in direction with the length of the side of the building, most of the damages are found on the border between the lower and upper floors. To explain such regularities, it is possible to imagine the

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following mechanism of interaction of a seismic wave with a building: the surface waves of Rayleigh and Love, carrying the main energy from the source of the earthquake, try to drag the building "grabbing" it for the ground, while the upper floors try to stay in place. Also, if the building is placed along the length of the wave propagation side, it can fall on two crests of running waves while experiencing maximum deformations. While buildings falling in the field of surface waves when they are perpendicular to the front are equally lowered and rise on the crests of surface waves, while experiencing minimal deformations. As a result, in addition to translational and rotational vibrations caused by long seismic waves, short waves are generated in reinforced concrete and brick structures caused by the explosive destruction of brittle ferro-concrete and brick. Since modern computational packages do not have the ability to model such a complex inhomogeneous oscillation-wave mechanics, the subtleties of the interaction of the building with waves incident on the ground can be determined only by means of the calculation-experimental method. We used a multichannel system "Struna" with five three-component sensors in the frequency range from 0.1 to 400 Hz. By placing the sensors on the ground at the base of the building and the building itself in height, in addition to the parameters of the oscillation periods along the axes and its attenuation decrements, we obtain acceleration parameters at any points of the building at different directions of the seismic wave approach, as well as pulsed cracking of micro-destructions in structures. The seismic impulse effect can be simulated by impacts of heavy load on the ground, the sensitivity of the sensors allows to detect the impacts of a sledge hammer weighing 10 kg at a distance of 10 m from the building.

To estimate the normative values of the oscillation periods along the X and Y axes, one can use a well-proven relationship of the type (Equation 1):

$$T_x = (k \times H)/(\sqrt{g} \times X) \qquad (1)$$

Where H-height of the building, m;
K-coefficient that takes into account the structural features of the building;
G is the acceleration of free fall;
X, Y is the length or width of the building in m. To calculate the period along the **Y** side, instead of **X**, the value of the side **Y** is substituted into formula (1).

The situation is more complicated for calculating the variations in the height **Z**, the authors propose the following relationship (Equation 2):

$$T_z = (k \times \sqrt{(X^2+Y^2)})/(2 \times \sqrt{g} \times Z) \qquad (2)$$

These dependencies were verified by the authors in experimental studies and using numerical calculations and the results of the comparison gave good convergence [1]. And, still, how to establish a boundary between the upper and lower part of the building, where the maximum destruction takes place.

It is proposed to establish the destruction boundary by more frequent installation of sensors along the height of the building and the creation of impulse loading along the long side. We apply a dependence of the type (1) to determine the boundary of the possible formation of cracks for this from Fig. 1, we use the frequency of the second maximum, considering it the main frequency of the attempting to detach the upper part of the building, then:

$$T_x = (k \times H)/(\sqrt{g} \times X)$$

Substituting the values of the parameters of Building No. 1, we obtain: $0.316 = (0.343 \times H)/(\sqrt{9.8} \times 25.91)$, where **H**- height of the building, m.

K-coefficient that takes into account the structural features of the building = 0.343; **G** is the acceleration of free fall; 9.8 m/s^2 **X**, is the length or width of the building, equal to 25.91 m. Then **H** = 15 m.

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Thus, when designing buildings and structures for seismic action, it is necessary to take into account the influence of incoming surface seismic waves. It is important to establish a boundary dividing the building into the surface and upper parts. For a detailed quantification of the parameters of the rigidity of the building and the boundary of separation of the upper part of the building from the lower one, it is proposed to apply the calculation and experimental approach.

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