Simulation of the structure of a multistory building with seismic isolation and the testing technique on a laboratory bench under dynamic ((seismic) impacts)

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Abstract. The article presents the main provisions of modeling multi-story buildings with seismic isolation, the characteristics of the seismic isolation device, structural elements and materials, the methodology for conducting experimental studies on a laboratory vibro-stand under dynamic (seismic) effects and the results of the modeling.

1 Introduction

At the present stage of the development of Structure Dynamics science, methods for calculating the seismic resistance of various surface and underground structures are being developed. Such studies include a number of scientific researchers conducted in the field of seismic resistance calculations for buildings and earth dams.

Articles [1, 2] are devoted to the dynamic problems of the strained state of earth dams under seismic impacts. A method was developed for solving wave problems for determining the stress-strain state of earth structures, in particular earth dams. Using the finite difference method, calculation formulas and an algorithm for solving problems were developed.

The article [3] is devoted to the dynamic problems of the deformed state of earth dams under seismic influences. A method for solving wave problems was developed to determine the stress-strain state of earth structures, in particular, earth dams. Using the method of finite differences was developed calculation formulas and an algorithm for solving problems.

Articles [4,5] are devoted to the theoretical calculation of the box-shaped structure of large-panel buildings for dynamic impacts, taking into account the spatial work of transverse and longitudinal walls under the dynamic impact, given by the base movement according to a sinusoidal law. Methods for numerical solutions to the problem of contact interaction of beam and plate elements of a box structure of a building were developed.

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The study in [6] is devoted to the numerical solution to the problem of transverse vibrations of a multi-story building in the framework of a solid slab model under seismic action. A cantilevered anisotropic plate is proposed as a dynamic model of the building. The model was developed within the framework of the three-dimensional dynamic theory of elasticity and takes into account not only structural forces and moments but also bimoments.

Articles [7] consider the development of the theory and method for calculating thick lamellar structures. A detailed analysis of well-known publications devoted to this problem is given. A theory and a method for estimating the stress-strain state of thick lamellar structures within the framework of the three-dimensional theory of elasticity were developed. In this study, the results of the calculation of a multi-story building for seismic resistance, obtained using the linear-spectral method (LIRA-SAPR SP), are presented. The choice of constructive solutions for the buildings, their design and calculation for seismic resistance should be conducted with the participation of specialized research-and-design organizations. In accordance with the current norms and principles for ensuring the seismic resistance of multi-story residential buildings, special attention must be paid to interpreting the law of seismic action on the basis of calculations.

The study in [8] considers the problem of seismic resistance of multi-story buildings with a sliding support. The calculation takes into account the vertical component of seismic effects in the form of real accelerograms. As a result of the calculation, the dynamic characteristics of the building with seismic isolation were determined.

In [9,10], the results of assessing the technical condition of existing buildings of preschool institutions built in seismically active regions of the republic in different years are presented; they take into account the requirements of various standards of earthquake-resistant construction. As a result, relevant recommendations are given for strengthening structures and ensuring the seismic resistance of load-bearing structures.

In [11], four-story and nine-story buildings were studied with a set of three earthquake records and it was shown that the use of a sliding foundation does not always lead to a significant decrease in the shear force on the floors of the building and that the vertical component of the seismic action has a significant effect on the shear vibrations of the building.

In [12], the influence of linear and nonlinear models of the foundation interaction with the foundation soil on the vibrations of a multi-story building under seismic effects was studied. In the studies, the building was designed for seismic impacts, taking into account rigid, elastic, elastic-plastic and viscoelastic models of the interaction between the foundation and the foundation soil.

The study in [13] considers the organization and conduct of dynamic tests of a multi-story residential panel building. For dynamic tests, a software and hardware complex was developed that implements the standing wave method and makes it possible to determine the dynamic characteristics of a building by registering microseismic vibrations of building structures. Based on the results of dynamic tests, the actual natural (resonant) frequencies and modes of oscillations of building structures were determined. From the analysis of the distribution of peak values of the amplitudes of natural vibrations, we have identified dangerous zones for the occurrence of destructive processes in the ground of the building foundation, affecting its safe functioning.

Reference [14] considers damage and destruction of building structures by fire and other thermal effects. The research method consists in developing a cellular model of a heat-insulated plate based on the localization of a heat source in a certain position above the plate and characterized by the temperature distribution in the cells. The evolution of this distribution is a transition probability matrix that describes the change in thermal conductivity along with the plate in two directions and in terms of source functions.

The study in [15] presents the results of experiments with samples of round concrete, and related to them differential (changing in depth) structural characteristics of concrete subjected to centrifugal molding and vibro-forming.

In [16], an analytical calculation of the brickwork of a barrel-shaped vault is considered, its structure of the material has a pronounced variability of elastic constants. In regulatory documents, brickwork is considered a complex two-component building material with elastic-plastic properties. However, there are no clear recommendations that take into account the variability of the elastic properties of brickwork.

There are numerous studies devoted to the development of the theory of seismic stability. Various methods were developed for calculating buildings and structures for seismic effects, taking into account such important factors as seismic load, soil conditions of the area and design features of building structures. These studies include the publications of the authors of this article [17, 18].

In [19], an analytical calculation of the brickwork of a barrel-shaped vault was considered; the structure of its material has a pronounced variability of elastic constants. In regulatory documents, brickwork is considered a complex two-component building material with elastic-plastic properties. However, there are no clear recommendations that consider the variability of the elastic properties of brickwork. A mathematical solution to a fourth-order partial differential equation with two variables for an anisotropic orthotropic body in polar coordinates is given to create mathematical models that describe the change in the modulus of elasticity of the vault material.

A technology for the production of anorthite-based building ceramics using semi-dry powder pressing based on the sintering of raw mixes consisting of low-melting clay and blast-furnace sludge (BFS) in various proportions is presented in [20].

Reference [21] considers the foundations of buildings and structures laid of weakly viscoelastic soils and the features of the theoretical justification of their deformations. The need for this study is due to the discrepancy between the theory of seepage compaction and field and laboratory experiments. Within the framework of the proposed model, designs are constructed for solving problems of loading the soil surface with typical loads that describe the stress-strain state of each phase of a two-phase medium (soil skeleton + pore water), taking into account the residual pore pressure.

Hundreds of severe earthquakes occur every year; ground motion in the future is inevitable since it is caused by the global evolution of the development of the lithosphere of our planet that continues for tens and hundreds of millions of years. Unfortunately, it is impossible to predict the exact time, place, and intensity of the next tremors, and to prevent them.

It should be noted that most often natural disasters in the world turn into social and economic disasters due to the unpreparedness of society for the next manifestations of the elements. Destruction and human casualties can be significantly less if the preparatory work is conducted correctly, based on an increase in the level of training and the ability of the population and local authorities to withstand the aftermath of earthquakes.

The first step to reduce damage from earthquakes is to reliably conduct the seismic zoning of the territory, which depends on knowledge of the structure, its strength properties, the dynamics of the earth's crust and the entire lithosphere, regional seismicity and seismic regime, seismic geodynamic potential of a particular region and its main geological structures, features of attenuation of the seismic effect with distance and much more.

On the other hand, it is quite obvious that no matter how much progress is made in the future in predicting the occurrence of strong earthquakes and seismic zoning of regions, they will not replace the need for such protective measures for the population as the design and construction of new earthquake-resistant buildings and structures using modern construction technologies, building materials and methods of active seismic protection, as well as the reconstruction of existing ones that do not meet the requirements of earthquake-resistant construction.

In the modern world, the main method of combating earthquakes is to ensure the seismic safety of buildings and structures at the design stage based on the latest scientific achievements and to strengthen the building structures of operated facilities based on the results of instrumental and computational studies.

2 The main types of seismic isolation

Seismic isolation is a complex of devices with elastic, plastic, and viscous properties, dry friction and mixed properties, located between the foundation and the ground structure of buildings that absorbs the energy of seismic impacts [22].

The use of modern methods of active seismic protection of buildings and structures in elements of structures is the installation of seismic isolation: in supports - between the levels of the foundation and grillage, in the floor level of the building - devices with different properties in the form of a friction damper, a viscous and friction damper, elastic connections, and at the roof level - inertial dampers, pendulum-type dampers, and shock absorbers operating according to the law of communicating vessels [23].

Seismic isolation supports are one of the ways to dampen seismic effects in buildings and structures, they include multilayer rubber-metal supports, multilayer rubber-metal supports with a lead core, sliding supports, kinematic supports, elastic spring supports, arched lead supports, supports with a plastic property, and others [24].

Seismic isolation supports are usually installed between the foundation and the ground part of the building structure. In cases where the project provides for installation between floors, it is allowed to install supports only after the elaboration of design solutions based on the results of appropriate reasonable calculations.

The foundations of buildings and structures in the design of seismic isolation supports are built in accordance with the requirements of the following regulatory documents: KMK 2.01.03-19 "Construction in seismic regions"; ShNK 2.02.01-19 "Foundations of buildings and structures"; ShNK 2.02.03-21 "Pile foundations"; ShNK 1.02.09-15 "Engineering and geological surveys for construction"; KMK 3.01.02-00 "Safety in construction"; KMK 2.04.01-98 "Internal water supply and sewerage of buildings"; ShNK 2.04.08-13 “Gas supply. Design standards”; KMK 2.04.17-98 "Electrical equipment of residential and public buildings"; KMK 2.04.20-98 "Communication device for signaling and dispatching engineering equipment of residential and public buildings" and ShNK 3.02.01-19 "Earth structures, foundations and bases".

The foundations for seismic isolation supports are usually solid; if necessary, it is allowed to use strip, pile, and free-standing foundations. In this case, it is required that the foundations are connected to each other by means of rigid joints and form a single spatial rigid structure [25].

To ensure uniform distribution of horizontal and vertical loads over the seismic isolation support, it is necessary to design a system of rigid beams or a monolithic grillage structure. A system of rigid beams or a monolithic grillage must be fixed rigidly with the ground part of the building. During an earthquake, torsional deformation is not allowed due to the irregular shape of ground structures or the occurrence of eccentricity between the centers of mass and the rigidity of the building [26].

When ensuring the reliable operation of seismic isolation supports and the stability of the building, the mass of a system of rigid beams or a monolithic reinforced concrete grillage is important. The mass of rigid beams or a monolithic reinforced concrete grillage is determined based on the results of linear and non-linear calculations for dynamic effects, taking into account the mass and rigidity of the ground part of the designed building. The calculation

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additionally takes into account the margin of safety, which considers the most critical state of the building.

Depending on the design solution and the structural system of the building, systems of seismic isolating support in the form of dampers, shock absorbers, ties, lateral restraints, and others can be used simultaneously based on the results of dynamic calculations.

Seismic isolation supports must be installed at the same level and symmetrically along the building in order to ensure an even distribution of external influences. The distance between the supports is determined on the basis of the results of dynamic calculations and the boundary conditions of the supporting structures. The distance between supports and other adjacent structures located above the seismic isolation device is determined based on the results of dynamic calculations. At that, it is necessary to ensure the possibility of free movement of a rigid structure over seismic isolation under seismic impacts. When installing seismic isolation supports, it is required to provide the necessary points for monitoring the processes and replacing the devices.

To ensure the reliable operation of seismic isolation supports from vertical and horizontal impacts of the building, it is necessary to follow the technology of connecting the foundations and the ground structure of the building. Connection nodes must be designed on the basis of theoretical calculations and experimental studies. To prevent damage to communication pipes and power lines when a rigid structure is displaced over seismic support during an earthquake, flexible connections or expansion joints must be considered in the building design process. In this case, the movement of flexible joints should be greater than the movement of a rigid structure under the influence of an earthquake. It is required to provide the necessary technological places for monitoring and assessing the technical condition of seismic isolation supports at the basement level.

The level of fire safety of the seismic isolation support is realized in accordance with the requirements of the fire safety standards for buildings - ShNK 2.01.02-04 “Fire safety of buildings and structures”. Monitoring of seismic isolation supports and the technical condition of the building should be regularly conducted by specialized organizations. For special cases agreed with the State Authority for Architecture, Urban Planning and Construction, it is allowed to apply additional requirements from foreign standards codes if it is necessary to take into account the requirements of national regulatory documents in the design and construction of buildings and structures with seismic isolation.

Foreign regulatory requirements (territorial building codes, guidelines, recommendations, standards, specifications) applied in addition to national codes should not contradict the requirements of national codes and requirements, exceptions are subject to justification and verification.

3 Statement of the problem

The main disadvantage of the existing modern supports for active seismic protection is their fragility. In contrast to existing seismic protection systems, below, an unconventional seismic isolation method is proposed. In accordance with the proposed technology of seismic isolation, a seismic isolation layer is designed, located between the foundation of the building and the rigid ground structure of the building (Figure 1).

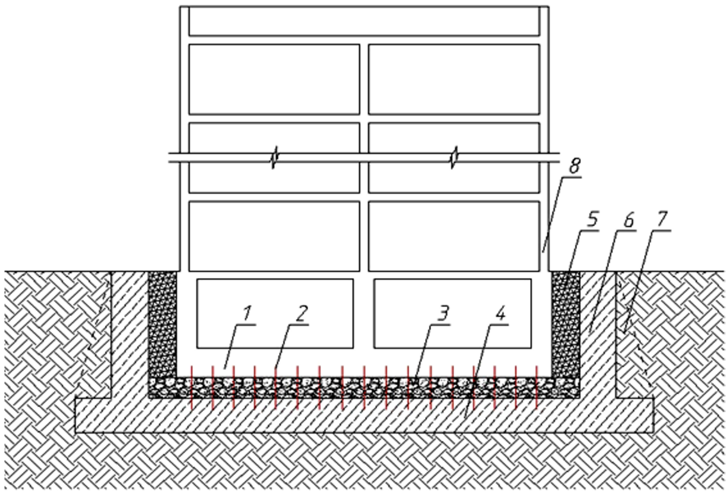

Fig. 1. General view of seismic isolation elements: 1 - reinforced concrete grillage; 2 - elastic rods; 3 - sand and gravel mix; 4 - solid reinforced concrete foundation; 5 - a mix of gravel or gravel-rubber crumbs; 6 - side walls; 7 - reinforced concrete buttress to ensure the rigidity of the foundation wall

The proposed method of active seismic protection consists of the following elements and their main functions: a monolithic solid foundation with a reinforced concrete base and walls 4; rigidly fixed rods 2 and sand-gravel mix 3, which perceive and transmit static and dynamic loads to the building foundations. The compressive pressure of the backfill layer 5, consisting of mixes of gravel or gravel-rubber crumb, filled between the side walls, acts on the side walls 6 from the displacement deformation of the rigid reinforced concrete grillage 1 under the influence of seismic forces.

The layer of sand-gravel mix perceives part of the vertical loads of the ground part of the building in accordance with the allowable deformation of the elastic rods. The sand-gravel mix causes vibration damping due to the mutual friction of the rods and the lower surface of the rigid grillage when it is displaced by seismic forces.

Elastic composite rods located in the sand-gravel mix are designed to absorb part of the vertical loads and to return the rigid structure of the grillage to its original position under vibrations. The correct selection of the mass of the upper rigid beam system and the design of the monolithic grillage based on dynamic calculations plays an important role in ensuring the stability of the building under seismic effects. Filling the sides of a rigid grillage in height with gravel or gravel-rubber mixes allows us to adjust the properties of friction and elasticity when the seismic isolation system is displaced.

To study the dissipative properties and interaction of elastic composite rods with a granular body, a small prototype of a solid foundation with a grillage was made and experimental studies were conducted on a laboratory vibration stand (Figure 2, a-d). According to the measurement results, the box dimensions are 0.45x0.46x0.17 m.

The elastic rods are made of GCR (glass-composite reinforcement) with a length of 0.17 m, a diameter of 0.006 m, and a working length of 0.1 m. The weight of one rod is 0.11 N. The weight of the steel box is 193.87 N. The volume inside the box is 0.022 m^3. The steel grillage dimensions are 0.355x0.363x0.0224 m. The weight of the steel grillage is 224.31 N.

In order to fill bulk materials around the perimeter of the grillage and the side walls of the solid foundation, a sheet with a height of 0.071 m was welded. There are 53 holes in the

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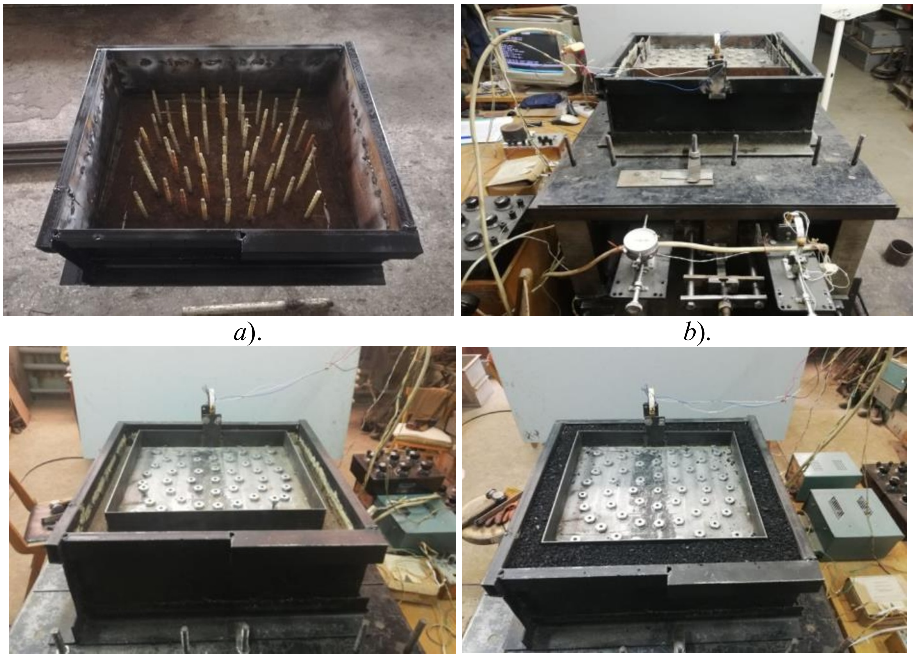
grillage for fastening.



a). *b*). *c*). *d*).

Fig. 2. *a* - a model of a solid foundation with a grillage, *b* - the testing of the model on a laboratory vibro-stand, *c* - base and side walls filled with sand, *d* - base filled with sand and side walls filled with rubber crumb

Experimental studies were conducted with different compositions of mixes: the base of the structure with a grillage filled with sand of different moisture content; the base filled with sand and the side walls filled with rubber crumb; the base made of sand and the side walls made of gravel; base and side walls made of gravel; the base and side walls made of rubber crumb; and base from the sand-gravel mix and side walls from rubber crumb.

4 Research results

Laboratory tests were conducted to determine the physical and mechanical properties of bulk materials used in experimental and computational studies. The coefficient of dry friction of the material was determined based on the method described. Table 1 shows the results of laboratory studies to determine the coefficient of dry friction of bulk materials and concrete with loose materials.

The density of bulk materials depending on the optimal moisture content and the density of dry soil is determined according to the requirements of state standards GOST 22733-2016. Upon request, tests are conducted in laboratory conditions using a special rammer in the following order:

- to measure the compaction capacity of bulk material, soil with natural moisture content was obtained from a construction site;
- a portion of soil was placed in the mold and rammed by 50 blows;
- the weight of 1 liter of compacted mass was measured and the density was determined;
- then the moisture content was increased in steps of 2%, and a similar cycle of tests was

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conducted;

– according to the results of laboratory tests, a graph of dependence of density vs moisture content was plotted. At the bending point, the maximum value of ρ_{max} is fixed at optimal moisture.

Table 1. Coefficients of dry friction for different materials

№	Material in a wooden box	Material in a cylinder (load)	Height of the movable end of the box when the load slides, m	Corresponding coefficient of dry friction, *f=tgα*
1.	Sand	Sand	0.28	0.5
2.	Gravel	Gravel	0.36	0.625
3.	Sand-gravel mix	Sand-gravel mix	0.35	0.62
4.	Land waste	Land waste	0.32	0.57
5.	Rubber-gravel mix (RGS)	Rubber-gravel mix (RGS)	0.36	0.625
6.	Rubber granule (RG)	Rubber granule (RG)	0.3	0.53
7.	Sand	Concrete	0.28	0.5
8.	Gravel	Concrete	0.35	0.62
9.	Sand-gravel mix	Concrete	0.32	0.57
10.	Land waste	Concrete	0.32	0.57
11.	Rubber-gravel mix	Concrete	0.34	0.6
12.	Rubber granule	Concrete	0.33	0.59

Determining the highest density of soil allows us to understand at what value the settlement under the foundation will be the smallest. Table 2 below shows the values of the optimal moisture content depending on the sand density by the size of the fraction. The classification of soil according to the size of the fraction and the grain composition of loose ground was accepted according to the data from the regulatory document.

Table 2. Optimal moisture content vs sand density

Types of sand	Fraction size, mm	Ranges of	
		optimal moisture content, w_{opt}, %	density of dry soil, ρ, t/m^3
Coarse and medium size sand	from 0,5 to 1 and from 0,25 to 0,5	8 - 12	1.75 - 1.95
Fine sand	from 0,25 to 0,05	9 -15	1.65 - 1.85
Dusty sand	from 0,01 to 0,05	14 - 23	1.6 - 1.82

Soil is generally compacted to a certain degree of density, expressed through the compaction coefficient k_{com}, which is the ratio of the set or actually obtained values of the compacted soil ρ_d to its maximum value according to the standard compaction $\rho_{d,max}$:

$$k_{com} = \frac{\rho_d}{\rho_{d,max}}$$

Figure 3 shows the experimental data in the form of graphs of the compaction of sand with different fractions and sand-gravel mix depending on the impacts of the stamp. As a result of the analysis of the graphs, it can be seen that the required soil compaction can be achieved with at least 40 impacts of the stamp, depending on the moisture content and fraction of the soil composition.

Laboratory tests were performed to determine the resistance of one rod in bulk material using a dynamometer back guy. The maximum measurement value of the dynamometer is 0.1 kN.

After filling and compacting the bulk material in a steel box, using a dynamometer in the horizontal direction, the displacement under bending of the rod and the back guying force in the wire were measured.

Experimental studies were conducted to determine the flexural rigidity of elastic composite rods depending on the back guying force. The results of the study of glass-composite reinforcement (GCR) with different diameters and filling of compacted bulk material in a steel box were obtained.

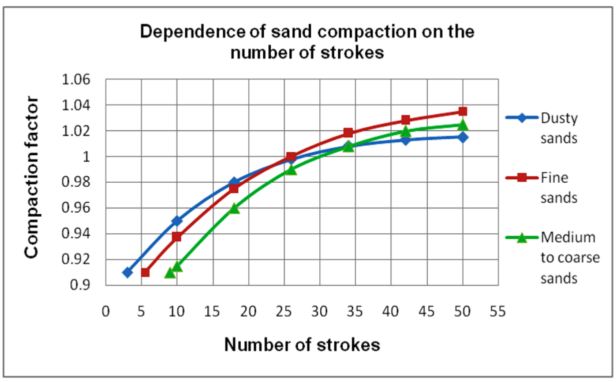

Fig. 3. Compaction of loose soils depending on the number of the impacts of the stamp: DS - dusty sand; FS - fine sand; CMS - coarse and medium sand

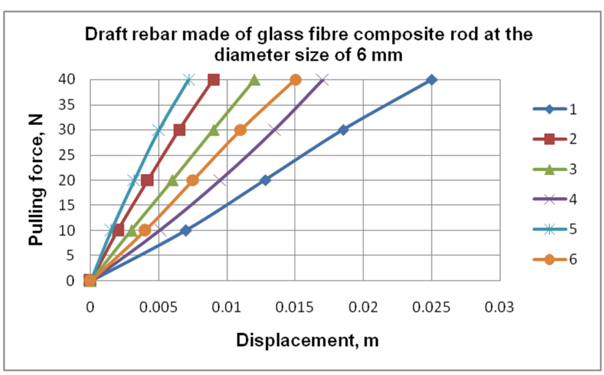

Fig. 4. Dependence of the back guying force and the displacement of the GCR rod with cross-sectional diameter of 6 mm

As an example, Figure 4 shows graphs of the dependence of the back guying force on the rod displacement with a cross-sectional diameter of 6 mm from GCR with various stages of filling:

1- rod displacement without filling loose bodies; 2- rod displacement in sand-gravel filling; 3- rod displacement in gravel filling; 4- rod displacement in sand filling; 5- rod displacement in land waste filling; 6- rod displacement in rubber-gravel filling.

The proposed seismic isolation consists of loose material and GCR reinforcements rigidly fixed to the lower part of the solid foundation and the upper part of the grillage. When the foundation of the building vibrates, one of the main parameters is the cohesion of the reinforcement to concrete. Experimental studies were performed to determine the tensile strength of GCR with concrete with a change in the diameter of the reinforcement. In the manufacture of a concrete sample, class B25 concrete was used. Laboratory studies to determine the cohesion of GCR to concrete were performed according to the requirements of the Interstate Standard GOST 31938-2012 "Composite polymer reinforcement for reinforcing concrete structures. General specifications" (ISO 10406-1:2008, NEQ).

The tensile and cohesion strength of glass composite reinforcement with concrete was determined using an electro-hydraulic servo-controlled universal testing machine WAW-1000B. The WAW-1000B universal testing machine is a computer-controlled and manually operated hydraulic loading system; the main motor controller is fixed separately. With the testing machine, experiments (on tension, compression, bending, cutting, etc.) can be conducted with metal and non-metal composite materials.

Cohesion of GCR with concrete; Shear stress, MPa; Displacement, mm

Dependence of sand shear stress vs displacement under bending; Shear stress, MPa; Displacement under bending, mm

The size of a concrete sample of class B25 was 0.15x0.15x0.15 m in accordance with the standards GOST. The concrete was made with a stirrer and a vibrator was used to ensure consistency of the sample. A series of experimental studies on the rupture and cohesion of GCR with concrete samples were performed. Figure 5 shows the dependence curves of the cohesion of GCR with concrete for different diameters of elastic composite rods.

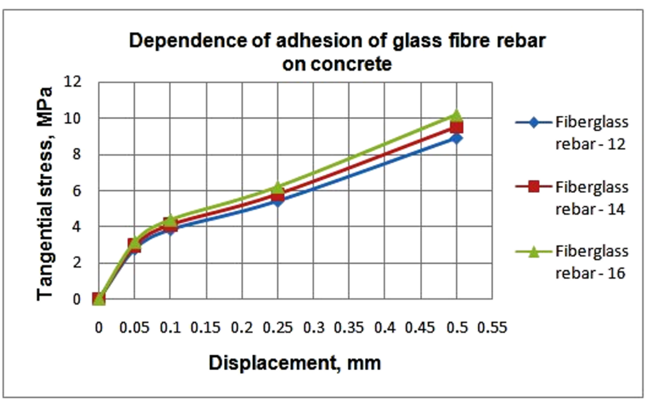

Fig. 5. Dependence of shear stress on displacements at different diameters of the GCR rods

The main physical and mechanical properties of bulk materials were studied in the laboratory with special instruments and equipment at the "Republican Center for engineering

Survey and Laboratory Research" at LLC "Uzbekhydroenergy" JSC.

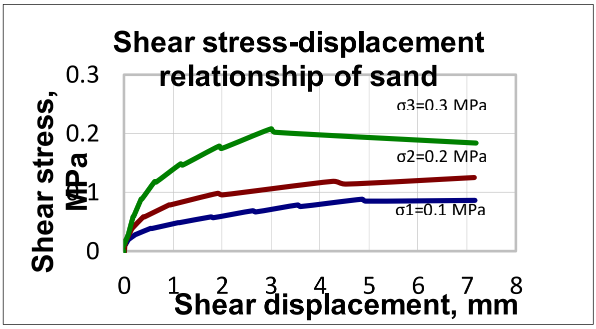

Fig. 6. Dependence of shear stress on displacement

The mechanical properties of sand were studied using the automated compression device GT 1.1.6 and single-plane cut automated device KD GT7.2.2 and GT7.2.5. The process of preparation of devices and the rules for testing bulk materials are detailed.

The results of the study of a sand sample in relation to the change in subsidence, normal and shear stress, as well as shear stress at shear displacement were obtained. Figure 6 shows the dependence of shear stress on shear displacement.

Strain of the stamp of sand-gravel mix; Vertical pressure, MPa; Vertical displacement, mm

The shear of coarse-grained soil was conducted using a special shear unit installed in the laboratory of the Republican Center for Engineering Survey and Laboratory Research at LLC JSC Uzbekhydroenergy. The shear installation allows us to determine the angle of internal friction and cohesion of coarse-grained soil under shear, as well as the relationship between soil stresses and strains, taking into account vertical pressure under compression and stress between carriages at the shear limit. The equipment consists of lower and upper carriages, filled with coarse soil, a power frame and a supporting part. The volume of lower and upper carriages is 287 cm^3.

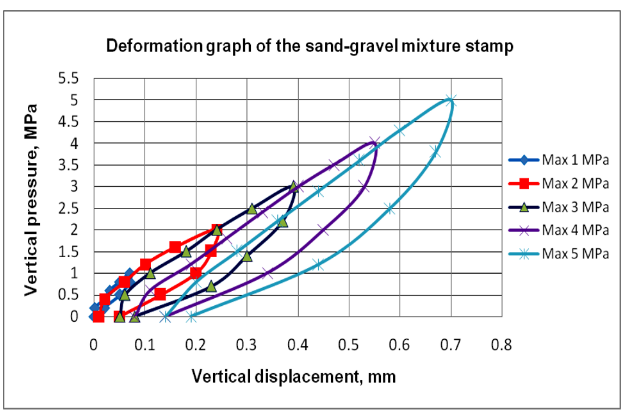

Fig. 7. Dependence of multiple loading and unloading of the stamp

In a shear installation, it is possible to test coarse-grained soil in a fraction size of up to 140 mm. The basic principle of operation of the installation is: lower and upper carriages are filled with coarse soil, and a stamp with an area of 65.5x65.5 cm2 is installed in the middle of the power frame. The upper supporting part, installed in the lower part of the servo cylinder, has an area of 36x36 cm2. With repeated tests, it is known that the weight of filling carriages with pebbles was 610-625 kgf. Each servo cylinder has the ability to give an external force of up to 1500 kN. Hydraulic manual servo cylinders are installed at the top of the stamp between the support beam of the power frame and in the horizontal direction to shear the equipment carriages in the support part of the installation. In order to measure the movement of the carriages and the upper stamp in the horizontal and vertical directions, steel rulers are attached to the installation to measure the deformation before and after the displacement of the carriage.

Using the shear installation, experimental studies were performed to study subsidence, and determine the relationship between shear stress and shear displacement, as well as the change in fine earth in the composition of the sand and gravel mix, used in the study of the proposed seismic isolation. The results obtained are shown in the form of graphs, for example, Figure 7 shows the dependence of multiple loading and unloading of the stamp.

Shear of the sand-gravel mix with a change in the content in the composition of fine earth m<5 mm; Shear stress, MPa; Normal stress, MPa.

In addition, in a uniaxial shear device, studies were conducted on the dependence of the sand-gravel mix with a change in the content of fine earth m<5 mm under shear. The resulting diagrams of the relationship between stresses and displacements under shear are shown in Figure 8.

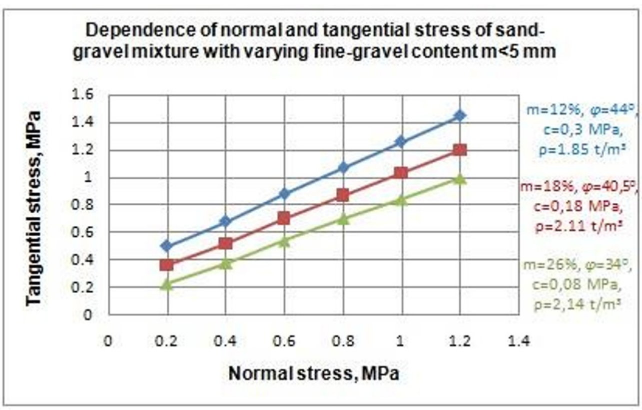

Fig. 8. Dependence of normal and shear stresses of the sand-gravel mix with a change in the content in the composition of fine earth m<5 mm

Studies were conducted on the dependence of shear stress with shear displacement of a sample of sand-gravel mix on a triaxial compression device GT 1.3.7. A sample was made of a sand-gravel mix according to the required mass and studies were performed in the sequence indicated in the guidelines. The obtained results of the dependence of shear stress and shear displacement of a sample of sand-gravel mix with constant normal stress are shown in the form of graphs in Figure 9.

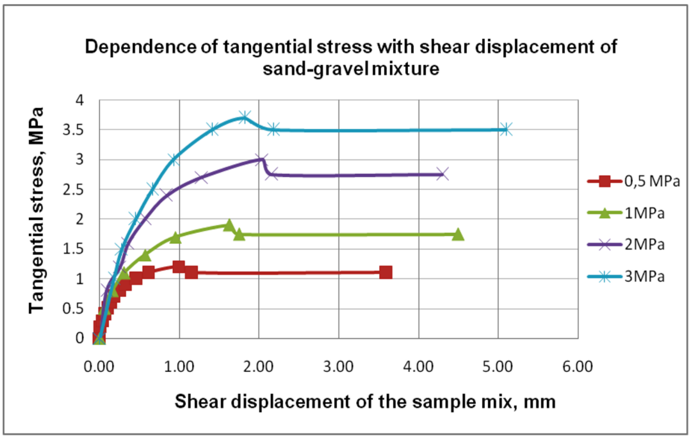

Fig. 9. Dependence of shear stress on shear displacement

Shear stress vs displacement of the sand-gravel mix under shear; Shear stress, MPa; Sample displacement under shear, mm.

The grain size composition of the sand-gravel mix sample was analyzed. The grain size composition of the gravel-sand mix complies with the Specifications and GOST 23 735-79. The results obtained from the analysis of particle size distribution are shown in Table 3. The results of studies to determine the coefficient of dry friction for materials are given in Table 1.

Table 3. Characteristics of fraction particles

Fraction size, mm	0.1	0.25	0.5	1.00	2.0	5	10	20	40	60	80
Fraction weight, kg	15.3	5.60	7.90	6.85	5.20	8.64	11.34	10.60	15.90	17.60	14.60
% content of each fraction	12.8	4.69	6.61	5.73	4.35	7.23	9.49	8.87	13.30	14.72	12.21
% content of fractions	12.8	17.5	24.1	29.8	34.2	41.4	50.89	59.76	73.06	87.79	100.0

Before starting a serial experiment to study the dissipative properties and the interaction of elastic rods with a granular body, experimental studies were conducted with a small model of a solid foundation with a building grillage (Figure 2). Experimental studies were conducted on a small vibro-stand at various intensities of external impact. The external impact was created with a special device for back guying the platform of the vibro-stand. The vibration table of the vibro-stand is fixed on four elastic plates, which can be adjusted vertically using a movable mount and the required rigidity of the elastic plates can be set.

As a result of processing the results obtained on the vibro-stand with a change in the number of elastic rods and filler from loose bodies, a rational option of the number of rods and filler for seismic isolation was chosen. Figures 10 and 11 show vibration records of the vibrating table and grillage with 25 elastic rods filled with sand and sand-gravel mix.

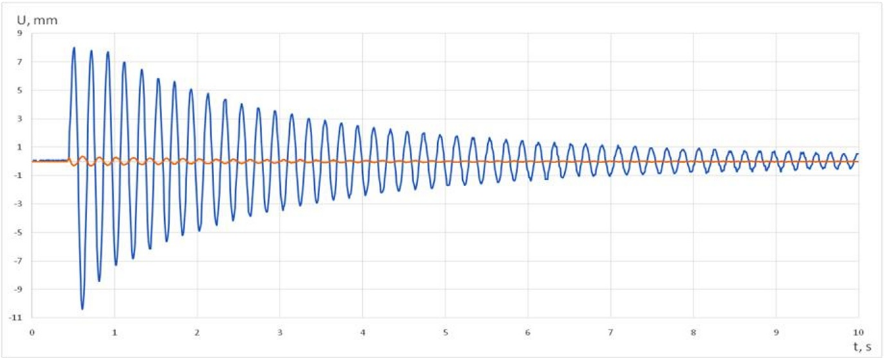

Fig. 10. Recording vibrations of the vibrating stand and grillage with 25 elastic rods filled with sand

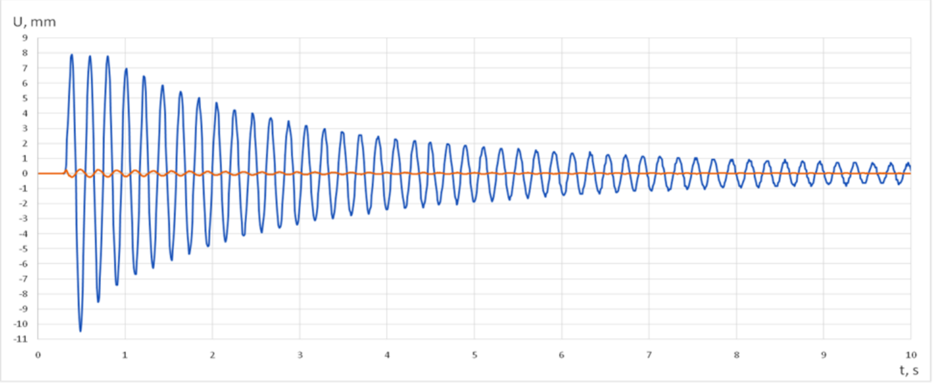

Fig. 11. Recording vibrations of the vibrating stand and grillage with 25 elastic rods filled with sand and gravel mix

5 Conclusion

1. Unlike existing seismic protection systems, the method of active seismic protection of buildings and structures proposed consists of a monolithic solid foundation with a reinforced concrete base and walls, rigidly fixed by composite rods filled with sand and gravel, which perceive and transmit static and dynamic loads to the building foundations. The compressive pressure of the backfill layer of mixes of gravel or gravel-rubber crumb, filled between the side walls, acts on the side walls, protecting the rigid reinforced concrete grillage from displacement deformation under the influence of seismic forces.

2. The layer of sand-gravel mix perceives part of the vertical loads of the ground part of the building in accordance with the allowable deformation of the elastic rods. The sand-gravel mix causes vibration damping due to the mutual friction of the rods and the lower surface of the rigid grillage when it is displaced by seismic forces.

3. Elastic composite rods located in the sand-gravel mix are designed to absorb part of the vertical loads, as well as to return the rigid structure of the grillage to its original position under vibrations. The correct selection of the mass of the upper rigid beam system and the design of the monolithic grillage based on dynamic calculations plays an important role in ensuring the stability of the building under seismic effects. Filling on the sides of a rigid grillage in height from gravel or gravel-rubber mix allows us to adjust the properties of

friction and elasticity when the seismic isolation system is displaced.

4. In connection with linear and non-linear static and dynamic calculations when designing systems of seismic isolating supports, the design and implementation of this recommendatory design solution in buildings and structures require the implementation of the project together with the authorized State Design Specialized Research Institutes.

5. It is not allowed to design and construct buildings and structures with a system of seismic isolation supports without technical specifications developed jointly with design, architectural, urban planning, and construction organizations and specialized research institutes authorized by the State body in the field of seismic construction.

6. For the proposed solution of the seismic isolation support to work effectively, buildings and structures must be technologically protected from direct ingress of rainwater through aggregates in the side walls of the building grillage.

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