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Satbayev University

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ИЗВЕСТИЯ

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Satbayev University

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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VIBROSEISMIC PROTECTION OF BUILDINGS AND STRUCTURES AGAINST NATURAL AND TECHNOGENEOUS DYNAMIC IMPACTS

Abstract. In this article, the authors analyze results of their long-term researches on protection of buildings and structures against dynamic loads caused by the nature and/or human activities. They also give the grounds for necessity to provide vibration insulation of buildings, and show how to choose and calculate proper parameters for rubber vibroseismic insulators. Specifics of finite element method applied for static calculating the vibroseismic insulators is also described. In order to take into account weak compressibility of rubber, a moment finite element scheme was used, which assumes a triple approximation of the displacement vector components consisting of strain tensor and volume change function. Stress-strain state of the shock absorbers was determined for different standard sizes and diameters. The authors also describe two variants of calculation depending on the method of fixing the insulator's ends. In the first case, the ends are vulcanized to the metal plates. In the second variant, the ends are free and can move in a horizontal plane. Influence of ratio of the shock absorber height and radius to the strain state of a structure was also analyzed. In order to determine factual levels of the soil and pile vibration (in two horizontal and one vertical directions), vibrodynamic studies were carried out. The obtained vibration signals were registered by the one-component vibration transducers 731A (vibration sensors) produced by the Wilcoxon Research company (the USA). Then, the vibration records were processed by the specialized program "Seismic Monitoring". Based on the results of these studies, numerical calculations were performed in order to determine whether the predicted levels of the residential building vibrations are in compliance with the existing sanitary standards when exposed to real technogeneous loads. Vibrodynamic tests on vibration acceleration levels of the vibration-insulated reinforced concrete slabs and floors in residential building confirmed high effectiveness of the used vibroseismic insulation system with the rubber elements: the registered vibration acceleration levels in the residential building on all floors did not exceed acceptable levels set by the sanitary standards, and ensured comfortable living conditions under different dynamic impacts. The results of this work make it possible to design buildings with anti-seismic protection by using the designed rubber elements in accordance with the local conditions of the city of Almaty.

Key words: shock absorber, vibroseismic isolation, finite element method, sanitary standards.

Preface. The considered system of vibroseismic insulation consists of non-linear elements with high dissipative properties; it includes structures, which limit drift of the upper part of the building, and is resistant to wind loads.

The vibroseismic insulation significantly reduces not only dynamic loads, but also horizontal interstorey drift (wraps), and, therefore, significantly diminishes damage of the building supporting structures, cuts economic losses and provides comfortable living conditions for people. As a rule, all these advantages are provided at the design stage in accordance with national regulations. For example, according to the Ukrainian norms [1], when designing buildings with vibroseismic insulation, in addition to spectral calculation, it is also necessary to calculate dynamics by accelerograms obtained at the construction site. Similar provisions are fixed in the building codes of the Republic of Kazakhstan, which are also based on the European standards.

The authors of this work were among those who developed a lot of national regulatory documents among which is the National Construction Standard ДБН В.1-12:2014 "Construction in Seismic Regions of Ukraine", which is harmonized with Eurocode 8 "Design of Structures for Earthquake Resistance (EN 1998–1: 2004 Eurocode 8). These documents include the section "Design of Seismoinsulation Systems" enabling to design vibroseismic-resistant structures with a specified level of safety.

The purpose of this work was to calculate and validate parameters of the vibration insulation system for buildings and structures under dynamic effects caused by the nature and human activities. For the conditions of the city of Almaty, this technical solution of seismic insulation based on the rubber elements is innovative.

Grounds for necessity in vibroseismic protection of buildings under natural and technogeneous dynamic impacts. Let's consider vibroseismic insulation of a residential complex in the city of Lviv (Ukraine) at the address: Pid Dubom street, 26, located in a zone with dynamic impact of freight and passenger trains. This residential complex consists of three sections (6, 10 and 13 floors), each section is built on its own vibration-proof pile foundation. In order to resist to the dynamic impacts of the railway trains, foundations of the buildings were made in the form of monolithic reinforced concrete grillages on a pile foundation (cross section of the piles is 350×350 mm); thickness of the pile foundation grillages in the six-storey section is 600 mm and 800 mm in the rest sections.

Results of the full-scale dynamic studies at the construction site at a distance of 15-22 m from the railway showed the following: in case of no anti-vibration protection system, predicted excess of permissible vibration acceleration levels of the building floors was from 6 dB to 12 dB (2-4 times higher than the sanitary standards) in the octaves of 8 Hz, 16 Hz, 31.5 Hz, 63 Hz. In order to ensure comfortable living of people, normalization of vibration acceleration levels is given in the norms described in [1].

For reducing vibration levels of the buildings, an anti-vibration protection system was installed: a rubber vibroseismic insulator with diameter of 340 mm and thickness of 50 mm was installed on the head of each pile before concreting the slab of the grillage. In order to protect the structures of the grillage and cellars of the buildings against horizontal and vertical vibrations of soil, the designed system for vibration insulation consisting of polystyrene plates with thickness of 100 mm is installed between the external surfaces of the foundation slab, walls of the underground storeys and backfill soil.

These innovative anti-vibration systems are very effective for buildings: the calculated frequency of the building intrinsic vertical vibrations is 3.8-4.7 Hz, which is 3-12 times less than the frequency of the soil forced oscillations (15-80 Hz) when exposed to effects of the railway trains; levels of the floor vibration do not exceed permissible sanitary norms for the residential buildings [1] under seismic overloads (determined at 6 points); the calculated safety factor against overturning of the buildings is from 5.4 to 16.5, and at wind loads, the safety factor is from 101.6 to 196.6.

Experimental studies and calculation of elements for anti-vibration protection of buildings and structures. The solid cylindrical rubber elements made of natural caoutchouc were used as components of the system for anti-vibration and anti-seismic protection of buildings and structures. In view of practical use, calculations were performed, design and method of the elements installation were patented, design documentation was developed, and four types of samples – with diameter of 340 mm, 400 mm, 420 mm and 500 mm and height of 50 mm – were manufactured and tested. The following tests were carried out: static testing of their compressive and shear stiffness at various loads; and dynamic testing of stiffness and dissipative characteristics. The test procedure is presented in details in [2].

Both analytical and numerical methods are used for calculating the vibroseismic insulators. Among the numerical methods, method of finite element stands out due to its universality and adequate accuracy.

Let's consider specific aspects of applying this method for static calculation of the vibroseismic insulators. In order to take into account the rubber weak compressibility and to eliminate some other disadvantages of the traditional finite element method, a moment finite element scheme was proposed for weakly compressible materials [3]. Its effectiveness for calculating rubber shock absorbers is shown in [4].

Let's consider a spatial hexagonal finite element with a linear approximation of displacements.

According to the moment scheme for weakly compressible material, stiffness matrix for each separate element will be represented in the global Cartesian coordinate system $O'z_{1'}z_{2'}z_{3'}$ in the form of [5]:

$$\left[K^{k'm'}\right]=\left[K_D^{k'm'}\right]+\left[K_S^{k'm'}\right], \quad (k',m'=1,\ldots,3) \tag{1}$$

where we have shearing component

$$\left[K_D^{k'm'}\right]=[A]\left[F_{ij}^{k'}\right]^T\left[H_D^{ijkl}\right]\left[F_{kl}^{m'}\right][A]^T \tag{2}$$

and spherical component of the stiffness matrix

$$\left[K_S^{k'm'}\right]=[A]\left[F_\theta^{k'}\right]^T\left[H_S\right]\left[F_\theta^{m'}\right][A]^T, \tag{3}$$

where matrices of elastic constants, which take into account metric of finite element and describe shearing and bulk properties of the material, are determined, respectively, as:

$$\left[H_D^{ijkl}\right]=\int_{-1}^{1}\int_{-1}^{1}\int_{-1}^{1}2\mu g^{ik}g^{jl}\{\psi\}^T\{\psi\}\sqrt{g}\,dx_1dx_2dx_3, \tag{4}$$

$$\left[H_S\right]=\int_{-1}^{1}\int_{-1}^{1}\int_{-1}^{1}\lambda\{\psi\}^T\{\psi\}\sqrt{g}\,dx_1dx_2dx_3, \tag{5}$$

where $\{\psi\}=\{1,x_1,x_2,x_1x_2,x_3,x_1x_3,x_2x_3,x_1x_2x_3\}$ is vector of power functions, g^{ij} and g are components and determinant of metric tensor of the finite element coordinate system $Ox_1x_2x_3$, $(i,j=1,\ldots,3)$, and μ,λ are the Lamé constants.

Let's determine matrix $[A]$ in the relations (2) and (3) by using various representations of the displacement vector components in the global coordinate system. On the one hand, according to the moment scheme, we have the expansion of displacements in a series of power functions:

$$u_{k'}=\{\psi\}\{\omega_{k'}\}^T, \tag{6}$$

where $\{\omega_{k'}\}=\left\{\omega_{k'}^{(000)},\omega_{k'}^{(100)},\omega_{k'}^{(010)},\omega_{k'}^{(110)},\omega_{k'}^{(001)},\omega_{k'}^{(101)},\omega_{k'}^{(011)},\omega_{k'}^{(111)}\right\}$ is vector of displacement expansion coefficients.

On the other hand, displacements of any point of the body are determined through the shape functions and values of nodal displacements:

$$u_{k'}=\{N_L\}\{u_{k'}^L\}^T, \tag{7}$$

here $\{u_{k'}^L\}=\left\{u_{k'}^{(1)},u_{k'}^{(2)},u_{k'}^{(3)},u_{k'}^{(4)},u_{k'}^{(5)},u_{k'}^{(6)},u_{k'}^{(7)},u_{k'}^{(8)},\right\}$ is vector of nodal displacements, $\{N_L\}=(N_1,N_2,N_3,N_4,N_5,N_6,N_7,N_8)$ is vector of shape functions. The shape functions for the hexagonal finite element are described in the local coordinate system by the relations:

$$N_L(x_1,x_2,x_3)=\frac{1}{8}\left(1+x_1x_1^L\right)\left(1+x_2x_2^L\right)\left(1+x_3x_3^L\right), \tag{8}$$

where x_i^L is the i-th coordinate of the L-th node in the coordinate system of the finite element; $i=1, 2, 3$; $L=1,\ldots,8$.

By comparing expressions (6) and (7) with allowance for (8), we can express matrix of transition $[A]$ from power functions $\{\psi\}$ to the shape functions $\{N_L\}$, so that the following relation can be realized:

$$\{\omega_{k'}\}=[A]^T\{u_{k'}^L\}. \tag{9}$$

Matrix $F_{ij}^{k'}$ should be formed in such a way that, when constructing the stiffness matrix (2), components of the strain tensor can be represented as an expansion in a power series in the following form:

$$\varepsilon_{11}=e_{11}^{(000)}+e_{11}^{(010)}\psi^{(010)}+e_{11}^{(001)}\psi^{(001)}+e_{11}^{(011)}\psi^{(011)},$$

$$\varepsilon_{22}=e_{22}^{(000)}+e_{22}^{(100)}\psi^{(100)}+e_{22}^{(001)}\psi^{(001)}+e_{22}^{(101)}\psi^{(101)},$$

$$\varepsilon_{33}=e_{33}^{(000)}+e_{33}^{(100)}\psi^{(100)}+e_{33}^{(010)}\psi^{(010)}+e_{33}^{(110)}\psi^{(110)},$$

$$\varepsilon_{12} = e_{12}^{(000)} + e_{12}^{(001)}\psi^{(001)},$$
$$\varepsilon_{23} = e_{23}^{(000)} + e_{23}^{(100)}\psi^{(100)}, \quad (10)$$

where $e_{ij}^{(pqr)}$ are the coefficients of deformation decomposition determined by $\omega_{k'}^{(\mu\nu\eta)}$.

Matrix $F_{\theta}^{k'}$, which is part of the (3), is formed in a similar way. According to the moment scheme, the volume change function is determined by the relation:

$$\{\theta\} = \{\xi\}^T\{\psi\}, \quad (11)$$

where expansion coefficients of the vector $\{\xi\}$ are determined

$$\xi^{(\alpha\beta\gamma)} = \left.\frac{\partial^{(\alpha+\beta+\gamma)}\varepsilon_{ij}g^{ij}}{(\partial x_1)^{\alpha}(\partial x_2)^{\beta}(\partial x_3)^{\gamma}}\right|_{x_1=x_2=x_3=0}. \quad (12)$$

through the strain expansion coefficients

$$\xi^{(\alpha\beta\gamma)} = e_{11}^{(\alpha\beta\gamma)}g^{11} + e_{22}^{(\alpha\beta\gamma)}g^{22} + e_{33}^{(\alpha\beta\gamma)}g^{33}. \quad (13)$$

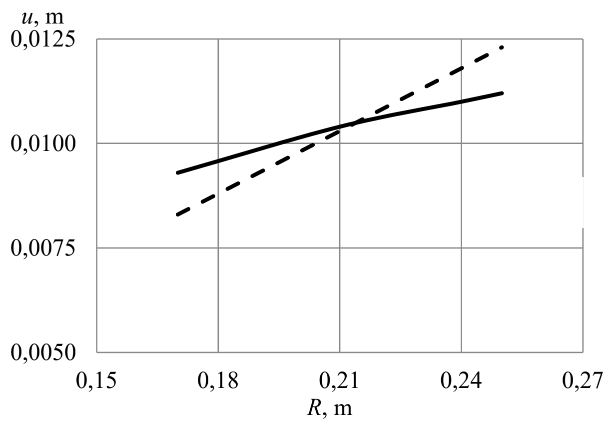
In the end, we can represent vector $\{\xi\}$ through the vector of displacement expansion coefficients $\omega_{k'}$:

$$\{\xi\} = \{F^{k'}\}\{\omega_{k'}\}. \quad (14)$$

Based on the described approach, a study of the stress-strain state of a number of sizes of shock absorbers of different diameters was performed.

Dimensions of the shock absorbers were: height $h = 0.05$ m, radius $R = 0.17$ m; 0.20 m; 0.21 m; 0.25 m; mechanical characteristics of rubber: elastic modulus $E = 5.38$ MPa, Poisson's ratio $\nu = 0.49$. Subsidence for all shock absorbers was accepted as $\Delta = 0.005$ m. Here, two calculation options are presented depending on the method of fixing the absorber's ends. In the first case, the ends are vulcanized to the metal plates. In the second variant, the ends are free and can move in a horizontal plane.

The maximum buckling of the shock absorber's lateral surface is shown in figure 1. While analyzing this characteristic, one can see manifestation of the rubber weak compressibility. With a greater h/R ratio, axial strain is compensated by radial deformation, the maximum value of which is greater in the case of the fixed ends than with free ends. In case of the free ends, shape of the deformed lateral surface is close to cylinder, and with the fixed ends it takes a barrel-like shape. This is true for any h/R ratios; though, in the second case, the less is this ratio the more pronounced is the barrel-like shape.



——— – fixed ends, ------- – free ends

Figure 1 – Buckling of the shock absorber's lateral surface

Technical solution and installation of the VSB. The designed vibroseismic insulating blocks are made in the form of solid or hollow rubber or rubber-metal elements, usually, base of the rubber is natural caoutchouc. In Ukraine, the VSB with diameter from 340 mm to 500 mm and height of 40-50 mm are used. In this research, their geometric parameters, as well as compressive and shear stiffness, were determined by the results of the calculation of the vibroseismically-insulated building. Rubber with maximum damping characteristics was chosen; when analyzing the rubber compounding, special ingredients were used (protective groups, antiagers, modifiers, etc.), which increase the VSB resistance to aging.

There are two ways for insulating buildings from vibration: to install the VSB at the level of the pile grillage (figure 2); or to install them in the basement of the building. In both cases, the upper part of the building, being under dynamic loads of natural and technogeneous character, is separated from the soil by the vibration insulators.

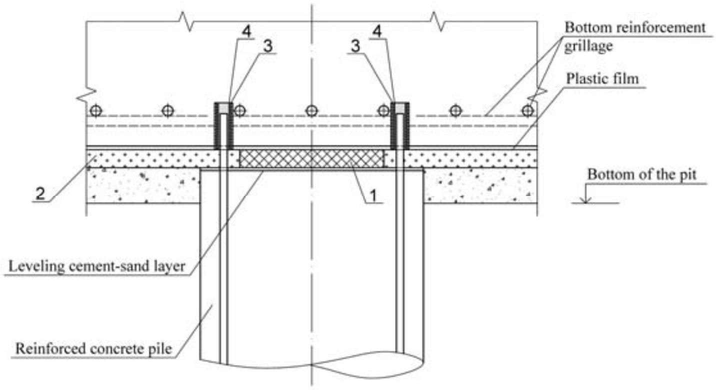


Figure 2 – Installation of the VSB at the level of pile grillage

One of the variants of the VSB installation on the pile is shown in figure 2: 1 – rubber VSB mounted on top of the pile head; 2 – a layer of expanded polystyrene; 3 – steel pipe; 4 – O-type rubber inserts placed between the reinforcing bars and the pipe: they improve damping characteristics of the vibroinsulation system and facilitate the grillage plate to drift relative to the pile.

This system for vibroseismic insulation of buildings and structures [6] has a number of important advantages: no resonance vibrations of the buildings are occurred during earthquakes or dynamic impacts of technogeneous character with spread or narrow-band acceleration spectrum; dynamic loads on the building are double less and even more; upper part of the building is protected from uneven subsidence of the foundation; natural frequency of the building's vibrations is 5-7 Hz at vertical oscillations and less than 1.0 Hz at horizontal ones; high damping ability of the protection system makes it possible to filter harmful vibrations in the wide frequency range; installation of vibroinsulators at the grillage level does not require additional fire protection and creates favorable conditions for making process of the rubber aging essentially longer.

Future trends of constructing buildings and structures with anti-vibration protection system. The main reasons for growing use of seismic insulation in the high-rise buildings is the necessity to reduce seismic loads (up to twice, i.e., by one point by the Ukrainian and EU seismic scales), to minimize relative horizontal interstorey drifting (wraps of the storey slabs) and, as consequences, to reduce consumption of materials, extent of structural damages and economic losses and to provide comfortable conditions for people during the earthquakes or under the effects of surface and underground transport (railway, subway, vehicles, vibrointensive equipment, etc.).

These factors present significant interest for investors and customers. According to the calculated data of departments for seismic resistance and economic researches in the State enterprise "State research institute of building constructions", it is possible to save from 35 thousand to 50 thousand US dollars per multi-storey (9-27 floors) residential house equipped with the seismic insulation due to the less consumption of concrete and reinforcement steel.

According to the State enterprise "State research institute of building constructions" and other literary sources, vibro- and seismic insulation allows to:

– prevent destruction of buildings and structures during earthquakes and under industrial impacts;

– cut the estimated costs of construction by 3-6 %;

– reduce material consumption for buildings and structures up to 10 %;

– reduce labour-intensiveness of construction by 4-6 %;

– expand the scope of typical series through developing regions with high seismic risk and increase height of the buildings with using the same structures.

In Ukraine, sixteen buildings were built and commissioned, including in Kiev: a ten-storey complex in Kikvidze street consisting of ten buildings with the system of vibroseismic protection against the impacts of trains of shallow-bedded underground railway, and complex of three twenty-storey buildings with the system of vibroseismic protection against the impacts of underground trains and surface transport in the Obolonskiy avenue (figure 7); in Lviv: a complex of three buildings with vibroseismic protection against railway transport in the Pid Dubom street. Construction of two 27-storey buildings with protection against the earthquakes has launched in Odessa, in the Genoese street (Odessa is located in the prone-to-earthquake zone due to the proximity to the Vrancea zone in Romania).

The test results indicate that the system of the building's vibroseismic protection against vertical vibrations in the whole and horizontal vibrations (at the level of the pile grillage) provides comfortable living conditions under dynamic impacts of subway trains, wind loads and microseismic vibrations. The results of this research can be used for designing high-rise buildings in the city of Nur-Sultan to protect them against excessive wind effects, and in designs of high-rise buildings in the city of Almaty with location near tectonic faults. For calculating seismically insulated systems with considering regional specificity, the calculation method [7,8] can be used. It is also recommended to arrange stations of engineering-seismometric service in the high-rise buildings [9,10].

The designed seismic insulation can also be used for reconstruction and reinforcement of buildings and historical and architectural monuments located in seismic hazard zones. In this case, the following advantages are obvious:

Use of the seismic insulation in the basement of the building preserves appearance of the building without destroying its architectural features;

Volume of works on reinforcing the upper isolated part of the building is significantly reduced: just the minimum design measures are to be performed in the aboveground part of the building, according to the requirements of the standard DBN B.1.1-12:2014;

When exposed to a calculated earthquake, reliability of the seismically insulated building is much higher than of buildings with traditional reinforcement; this is due to the fact that seismically insulated building stands significant deformation without structural damages during the seismic impact, while in building with traditional reinforcement, it is impossible to avoid crack formation and structural damages.

The designed vibration and seismic insulation is also recommended for repairing and restoration of historical monuments, hospitals, banks and other critical structures erected ages ago [11].

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ҒИМАРАТТАР МЕН ҚҰРЫЛЫСТАРДЫ ДІРІЛДІ СЕЙСМИКАЛЫҚ ТАБИҒИ ЖӘНЕ ТЕХНОГЕНДІК СИПАТТАҒЫ ДИНАМИКАЛЫҚ ӘСЕРДЕН ҚОРҒАУ

Аннотация. Мақалада ғимараттар мен құрылыстарды табиғи және техногендік сипаттағы динамикалық жүктемелерден қорғау жөніндегі көпжылдық зерттеулердің нәтижелері қарастырылады. Ғимараттардың діріл оқшаулау қажеттілігінің негіздемесі, параметрлерді таңдау және резеңке діріл оқшаулағыштарын есептеу ұсынылған. Дірілді сейсмикалық изоляторларды статикалық есептеу үшін ақырлы элемент әдісін қолдану ерекшеліктері келтірілген. Резинаның әлсіз қысылуын ескеру үшін штамм тензоры мен көлемнің өзгеру функциясын құрайтын орын ауыстыру векторының құрамдас бөліктерін үш есе жақындатудан тұратын ақырлы элементтің момент схемасы қолданылды. Түрлі диаметрдегі амортизаторлардың бірқатар стандартты өлшемдерінің кернеулі-деформацияланған күйі анықталды. Шеттерін бекіту әдісіне байланысты екі есептеу әдісі ұсынылған. Бірінші жағдайда, ұштары металл плиталарға вулканизацияланған. Екіншіден, ұштары бос және көлденең жазықтықта қозғалуы мүмкін. Амортизатордың биіктігі мен оның радиусының арақатынасы құрылымның деформацияланған күйіне әсері талданады. Топырақ пен қадалардың нақты діріл деңгейін анықтау үшін (екі көлденең және бір тік бағытта) вибродинамикалық зерттеулер жүргізілді. Діріл сигналдарын тіркеуді «Wilcoxon Research» (АҚШ) компаниясынан 731А маркалы бір компонентті дірілдеткіштер (діріл датчиктері) жүргізді. Діріл жазбалары мамандандырылған «Сейсмономониторинг» бағдарламасын пайдалану арқылы өңделді. Осы зерттеулердің нәтижелері бойынша нақты техногендік жүктемелер әсерінен тұрғын үй-жайлардағы болжамды діріл деңгейінің қолданыстағы санитарлық нормаларға сәйкестігін анықтау үшін сандық есептеу жүргізілді. Дірілмен оқшауланған темірбетон плитасы мен тұрғын үй едендерінің дірілүдеткіш сынамалары резеңке элементтерін қолдана отырып, діріл-сейсмикалық оқшаулау жүйесінің тиімділігін дәлелдеді: түрлі қабаттардағы тұрғын үй-жайлардағы тіркелген діріл үдеуінің деңгейі қажетті деңгейден аспайды, бұл динамикалық әсердің болуы жағдайында жайлы өмір сүруді қамтамасыз етеді. Жұмыс нәтижелері Алматы қаласының жергілікті жағдайына байланысты резеңке элементтерін қолдана отырып, сейсмикалық оқшауланған ғимараттарды жобалауға мүмкіндік береді.

Түйін сөздер: амортизатор, дірілді оқшаулау, ақырлы элемент әдісі, санитарлық нормалар

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ВИБРОСЕЙСМОЗАЩИТА ЗДАНИЙ И СООРУЖЕНИЙ ОТ ДИНАМИЧЕСКОГО ВОЗДЕЙСТВИЯ ПРИРОДНОГО И ТЕХНОГЕННОГО ХАРАКТЕРА

Аннотация. В статье рассмотрены результаты многолетних исследований по защите зданий и сооружений от динамических нагрузок природного и техногенного характера. Представлено обоснование необходимости вибросейсмоизоляции зданий, выбор параметров и расчёт резиновых вибросейсмоизоляторов. Представлены особенности применения метода конечных элементов для статического расчёта вибросейсмоизоляторов. Для учёта слабой сжимаемости резины использовалась моментная схема конечного элемента, которая заключается в тройной аппроксимации компонентов вектора перемещений, составляющих тензора деформаций и функции изменения объёма. Определено напряженно-деформированное состояние ряда типоразмеров амортизаторов различных диаметров. Представлено два варианта расчёта в зависимости от способа закрепления торцов. В первом случае торцы привулканизированы к металлическим пластинам. Во втором торцы свободны и могут перемещаться в горизонтальной плоскости. Проанализировано влияние соотношения между высотой амортизатора и его радиусом на деформированное состояние конструкции. Для определения фактических уровней вибраций почвы и свай (по двум горизонтальным и одному вертикальному направлениям) были проведены вибродинамические исследования. Регистрация вибросигналов осуществлялась однокомпонентными вибропреобразователями (датчики вибрации) марки 731А фирмы «Wilcoxon research» (США). Обработка записей колебаний проводилась с использованием специализированной программы «Сейсмомониторинг». По результатам этих исследований выполнены численные расчёты для определения соответствия прогнозируемых уровней вибраций в жилых помещениях существующим санитарным нормам при воздействии реальных техногенных нагрузок. Вибродинамические испытания уровней виброускорений виброизолированной железобетонной плиты и перекрытий жилого дома подтвердили эффективность системы вибросейсмоизоляции с применением резиновых элементов: зарегистрированные уровни виброускорений в жилых помещениях на разных этажах не превышают допустимых уровней по санитарным нормам, что обеспечивает комфортные условия проживания при наличии динамических воздействий. Результаты работы позволяют проектировать сейсмоизолированные здания с применением резиновых элементов применительно к местным условиям города Алматы.

Ключевые слова: амортизатор, вибросейсмоизоляция, метод конечных элементов, санитарные нормы.

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