doi: 10.18720/MCE.80.6

The seismic stability of facade system with facing by composite panels

Сейсмостойкость фасадной системы с облицовкой композитными панелями

V.M. Tusnina*,
National Research Moscow State Civil Engineering University, Moscow, Russia
D.A. Emelianov,
Center of Engineering Services and Technical Expertise, Moscow, Russia

Канд. техн. наук, доцент В.М. Тусина*,
Национальный исследовательский Московский государственный строительный университет, Москва, Россия
канд. техн. наук, ведущий инженер Д.А. Емельянов,
Центр инжиниринговых услуг и технической экспертизы, Москва, Россия

Key words: suspended facade system; composite cladding panels; notched hub mounting; seismic resistance; dynamic load; vibration platform; acceleration

Ключевые слова: навесная фасадная система; облицовка из композитных панелей; зубчатое узловое крепление; сейсмостойкость; динамическая нагрузка; виброплатформа; ускорение

Abstract. The hinged ventilated facades installing is a perspective technology of buildings decoration. Suspended facade systems are widely used for construction and reconstruction of residential, administrative, public and industrial buildings. Using suspended facade systems for decorating exterior walls is helping designers to solve the problems of thermal protection and architectural and artistic expressiveness of buildings by using modern heat-insulating and decoration materials. The finishing of facades with composite panels is especially effective for buildings erected in areas with seismic activity because the using of lightweight cladding leads to a significant reduction in the mass of external walls and to the reduction of seismic loads. In this article we present the results of the experimental study of bearing capacity and operational reliability under dynamic loads of hinged facade system with toothed nodal fastening of aluminum composite panels, which was developed in the Moscow State Construction University. The tests were conducted on a vibrating platform of a pendulum type by a vibrational (resonant) method, which allows to determine the power load simulating seismic actions in a wide range of frequencies, in the Central Research Institute of Building Constructions named after V.A. Kucherenko (CRIBC). The results of experimental studies clearly demonstrated the increased seismic stability of the structure with toothed nodal fastening of composite panels in comparison with facade systems having a similar type of cladding. We found out that the developed design is able to dissipate the energy from the dynamic load due to the presence of additional connections in the structural solution of the tooth assemblies and allow to quench the energy of the oscillation of the system under seismic influences.

Аннотация. В настоящее время перспективной технологией отделки зданий является устройство навесных вентилируемых фасадов. Навесные фасадные системы широко используются для строительства и реконструкции жилых, административных, общественных и промышленных зданий. Применение систем навесных фасадов для отделки наружных стен позволяет проектировщикам эффективно решать задачи тепловой защиты и архитектурно-художественной выразительности зданий, используя современные теплоизоляционные и отделочные материалы. Отделка фасадов панелями из композитных материалов особенно эффективна для зданий, возводимых в районах с сейсмической активностью, поскольку применение лёгкой облицовки приводит к существенному снижению массы наружных стен и, следовательно, к снижению сейсмических нагрузок. В настоящей статье приводятся результаты экспериментального исследования несущей способности и эксплуатационной надежности в условиях динамических нагрузок, разработанной в Московском государственном строительном университете, навесной фасадной системы с зубчатым узловым креплением облицовки из алюминиевых композитных панелей. Испытания проводились в ЦНИИСК им. В.А. Кучеренко на виброплатформе маятникового типа вибрационным (резонансным) методом, позволяющим определять силовую нагрузку, имитирующую сейсмические воздействия в широком диапазоне

Туснина В.М., Емельянов Д.А., Сейсмостойкость фасадной системы с облицовкой композитными панелями // Инженерно-строительный журнал. 2018. № 4(80). С. 62–72.

частот. Результаты экспериментальных исследований наглядно продемонстрировали повышенную сейсмостойкость конструкции с узловым зубчатым креплением композитных панелей в сравнении с фасадными системами, имеющими аналогичный тип облицовки. Установлено, что за счет наличия дополнительных связей в конструктивном решении зубчатых узлов, разработанная конструкция способна хорошо рассеивать энергию от динамической нагрузки, что позволяет гасить энергию колебания системы, имеющей место при сейсмических воздействиях.

1. Introduction

Various in design and finishing hinged facade systems (HFS) are widely used in building and reconstruction of buildings [1–6]. HFS allows to effectively solve energy conservation problems [7–9] and to give the building the necessary architectural look in the high tech style.

Thermotechnical and economic calculations [10–15] and studies on the operational reliability of ventilated facades [16–19] clearly demonstrate the effectiveness of HFS.

Facade systems with aluminum composite panels finishing (ACP) amount a great part in the total volume of applied facade systems in construction. The using facades with composite panels is especially effective for buildings erected in areas with seismic activity because the using of lightweight cladding leads to a significant reduction in the mass of outer walls and to the reduction of seismic loads [20–22].

There are some constructive solutions for fastening linings from aluminum composite material which meet the safety requirements under the action of dynamic loads. But these systems are characterized by increased material consumption and, correspondingly, low economic indicators. Some systems do not allow creating the required architectural appearance of the facade. This applies to systems in which the cladding is fixed with the help of visible rivets on the façade. Also designs fastening lining in such systems do not take into account the deformation elements from temperature effects [23-26].

The design of a hinged facade system with toothed lining fasteners made of aluminum composite panels was developed and researched in the Moscow State University of Civil Engineering. The fastening cladding elements in the design is carried out by the toothed connection hook with carriage bracket. The design of gear units is capable of receiving all horizontal and vertical loads while earthquakes due the L-shaped hooks, which are arranged specularly to each other. There is no need for temperature-strain joints due the absence of vertical and horizontal guides in the structure. There are special ventilated channels, arranged with cutouts in the lower sides of the cassettes made for airflow in the structure. The structural elements of the system are made of aluminum alloy. Finishing cassettes are inserted into the gear connection, but mounted on vertical guides, which reduces the complexity of installing such structures.

A detailed description of the constructive solution of the HFS is presented in the works [27–31].

The purpose of this article is to study the bearing capacity and operational reliability of the developed vented HFS with toothed lining fasteners made of ACP under dynamic loads, simulating the 7-9 point seismic and wind pulsation effects.

The HFS tests on a vibrating platform allowed to solve the following problems:

- to set dynamic indicators, physico-mechanical and operational characteristics of HFS with toothed lining fasteners made of ACP;
- to determine the scope of possible use of the developed HFS design, taking into account all requirements required for constructions erected in areas with seismicity of 7-9 points on the MSK-64 scale [32];
- to reveal the increased seismic resistance of the developed design in comparison with existing facade systems with a similar material consumption.

2. Methods

Experimental studies on dynamic loads simulating 7-9 point seismic and wind pulsation (at a height of 75 m from ground level) were carried out to assess the operational reliability of the HFS with toothed lining fasteners made of ACP (Figure 1). The tests were conducted on a vibrating platform of a pendulum type by a vibrational (resonant) method, which allows to determine the power load simulating seismic actions in a wide range of frequencies in the Research Institute of Building Constructions (TSNIISK) named after V.A. Koucherenko.

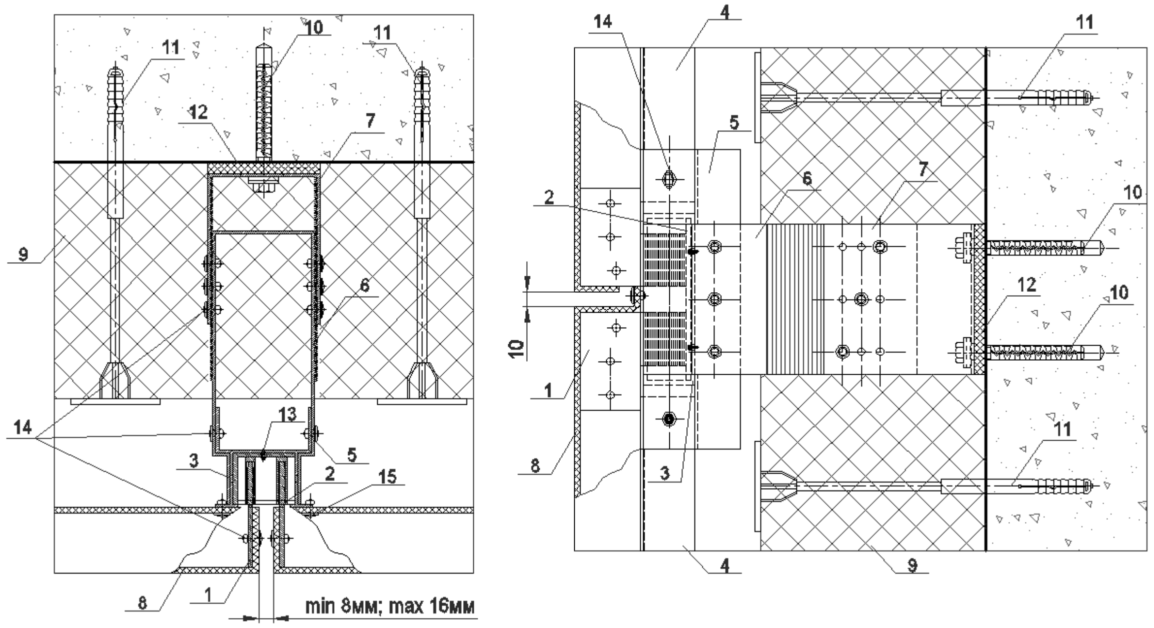

Figure 1. The HFS fastening unit: a – vertical joint; b - horizontal joint; 1 – the gear hook (iklya); 2 – the carriage gear bracket; 3 – the carriage; 4 – the drainage profile; 5 – the extension reverse part; 6 – the extension; 7 – the bracket; 8 – the HFS; 9 – the mineral wool insulation; 10 – the anchor dowel; 11 – the bowl dowel; 12 – the paronit cushion; 13 – the self-tapping screw; 14 – the exhaust rivet Ø 5 × 12 mm; 15 – the exhaust rivet Ø 3.2×10 mm

The study of the actual work of the developed design was carried out on two experimental models: "angular" – made from one HFS formed the facade angle and "fragmentary" – made from several HFS's bilateral facade of the experimental stand (Figure 2).

We used brackets with emission set at 100 mm, which were mounted on a stand with a vertical and horizontal step equal to 1200 mm for experimental models. The total overhang was 200 mm. To excite dynamic effects on the system under test, we used a pendulum-type vibration platform with a VID-12M vibrator (Figure 3). To control the given loads, the accelerometers were mounted on a vibration platform near the oscillation excitation source. The displacement and acceleration from the given loads were measured by six sensors mounted on the model (sensors 1-4) and on the platform (sensors 5,6) (Figure 4). Measuring, recording, processing and transmission of information from sensors were carried out using a specialized measuring and computing complex MIC-036. Automation of processing of strain-gauge records was carried out with the help of WinPOS software.

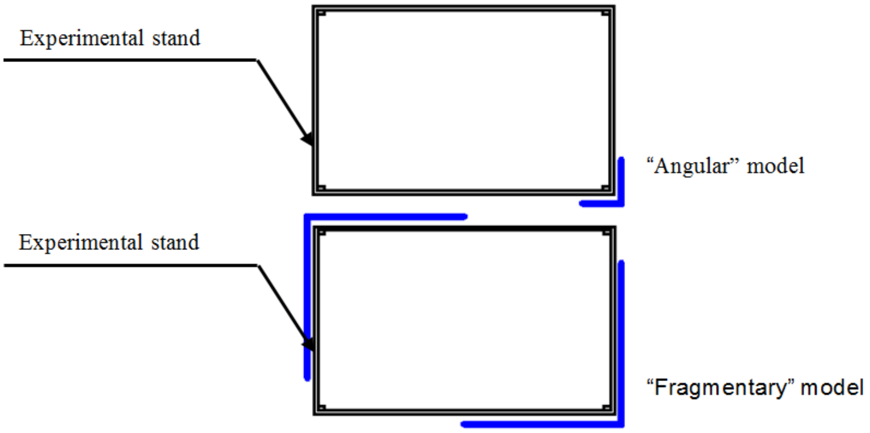

Figure 2. The scheme of the experimental stand

The HFS estimation of the limiting state was carried out on the basis of a comparative analysis of the test results with the data of the instrumental part of the macroseismic scale MSK-64 according to [15].

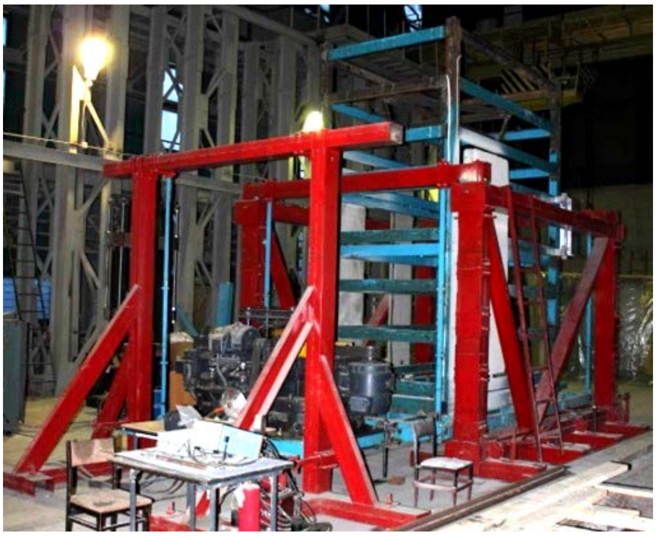

Figure 3. General view of the experimental equipment

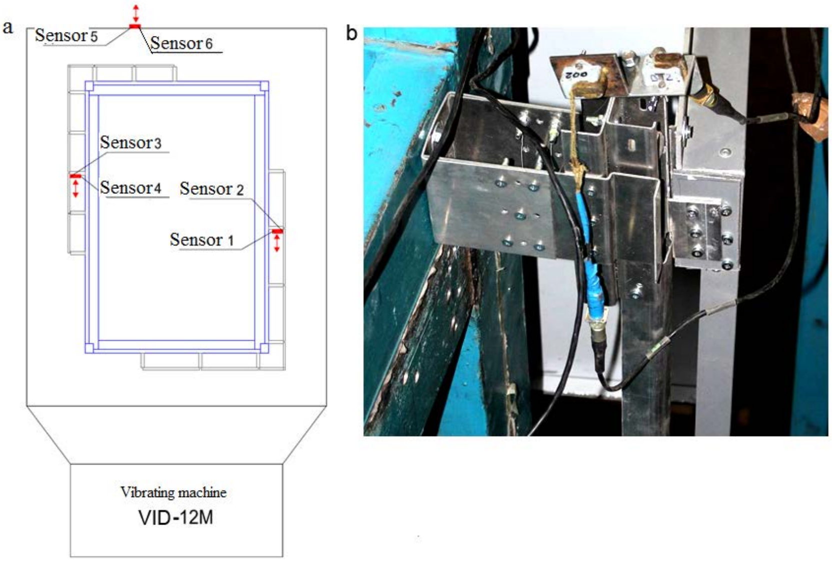

Figure 4. Experimental equipment: a – arrangement of sensors; b – system node with measuring equipment

Tests were carried out in several stages. The frequency spectrum varied from 0 to 10 Hz at the initial stage, with the amplitude of the movements of the vibrating platform unchanged. Then the amplitude value varied with the frequency assignment in the same spectrum. The duration of each stage of the dynamic loading of the system fragment was from 20 to 25 seconds. Acceleration levels of the vibratory platform corresponding to 7 ÷ 9 points on the MSK-64 scale and the levels of impacts corresponding to the resonance oscillations of the system were established based on the results of the first stage of the tests. Then repeated tests of the system were performed with combinations of the amplitude-frequency parameters of the vibratory platform corresponding to resonant oscillations of the system at 7 ÷ 9 points. The test duration was 40 ÷ 50 sec.

3. Results and Discussion

In the course of the test, the acceleration of the vibrating platform varied in the range from 0.4 to 5.05 m/s^2 according to the accelerometers. The oscillation frequencies of the system varied in the range from 1.6 to 7.8 Hz, the vibration amplitude of the vibratory platform – from 0.6 to 3.8 mm. The acceleration in different system points varied in the range from 0.01 to 30.82 m/s^2.

Accelerograms recorded from the sensors installed on the system fragment (sensors 1-4) and on the platform (sensors 5, 6) are shown in Figure 5.

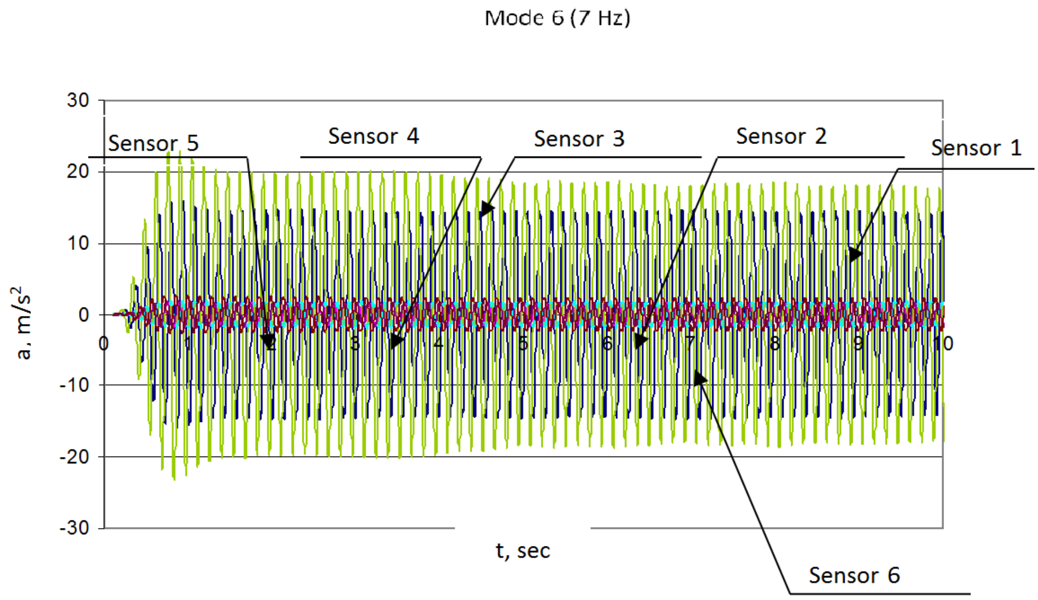

Figure 5. Accelerograms recorded from the sensors 1-6 (mm)

Centering and filtering of the accelerograms were made for a fragment of the developed system. Spectra of peak values of accelerations for sensors at various stages of loading are obtained using a fast Fourier transform. Spectra of peak values of accelerations for one of the stages of loading are shown in

The peak values of the oscillation frequencies were determined from the spectra. The values of displacements at various stages of loading were obtained by double integration of the accelerogram function.

Graphs of the dependence of accelerations and displacements on the frequency of system oscillations are obtained from the results of tests (Figures 7–14).

As can be seen from Figure 7, the maximum peak acceleration value with horizontal oscillations of the system of 36.0 m/s^2 at a frequency of 5.9 Hz was recorded by the sensor 3 installed at the top of the structure at an altitude of 3000 mm from the platform level. The peak acceleration value for the platform is equal to 5.1 m/s^2 is observed at frequencies of 3.3 Hz ÷ 4.0 Hz.

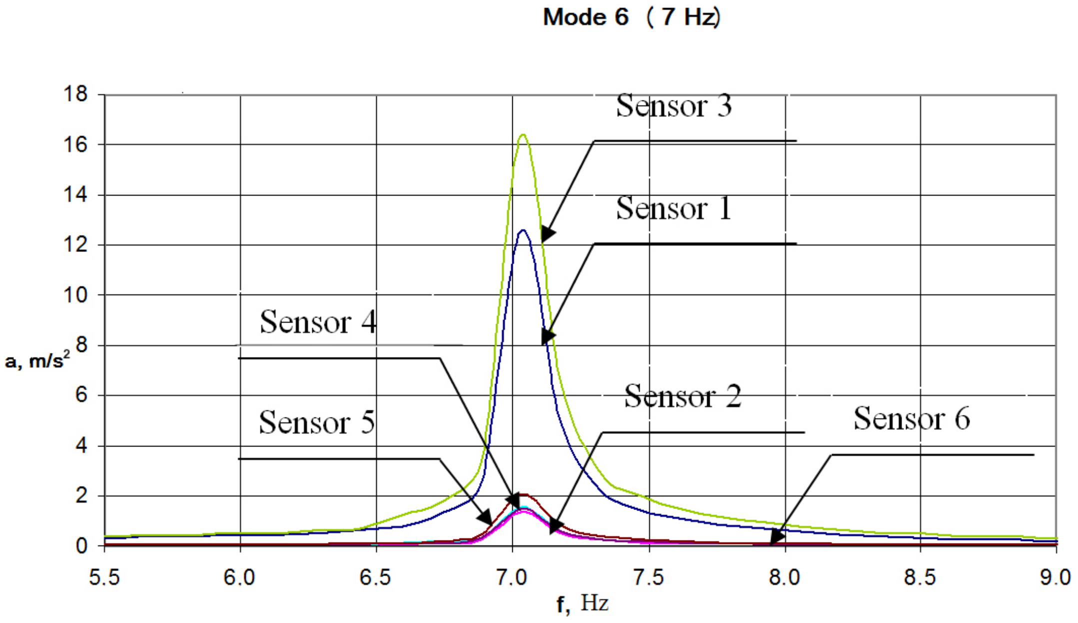

Figure 6. Spectra of peak values of accelerations for sensors 1-6

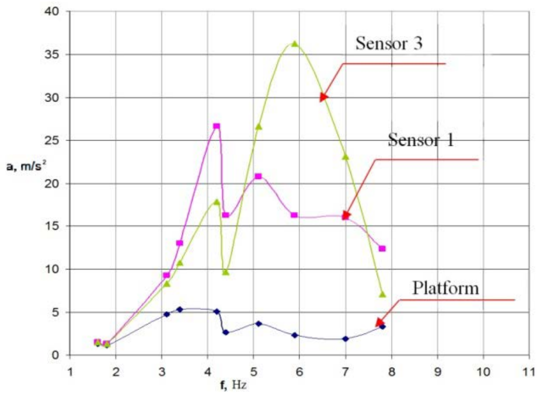

Figure 7. Graphs of the dependence of acceleration on the frequency of system horizontal vibrations

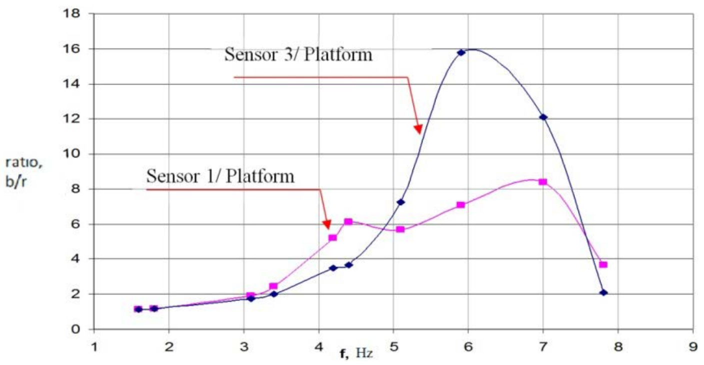

Figure 8. Graphs of the dependence of the relative acceleration σp "system-platform" on the frequency of horizontal oscillations

As can be seen from the graph in Figure 8, the acceleration value of the system upper part (sensor 3) considerably exceeds the acceleration of the lower part of the structure with the same frequency of horizontal oscillations (where σ_p is a dimensionless quantity equal to the ratio of the accelerations of the system and the platform).

The peak value of the system acceleration equal to 7.1 m/s^2 was recorded at a frequency of 5.9 Hz with vertical oscillations. The peak acceleration value of the platform, equal to 5.0 m/s^2, was observed at a frequency of 7.8 Hz. The maximum system acceleration at the same frequency of vertical oscillations is noted in the upper part of the structure, at the location of the sensor 4 (Figure 9).

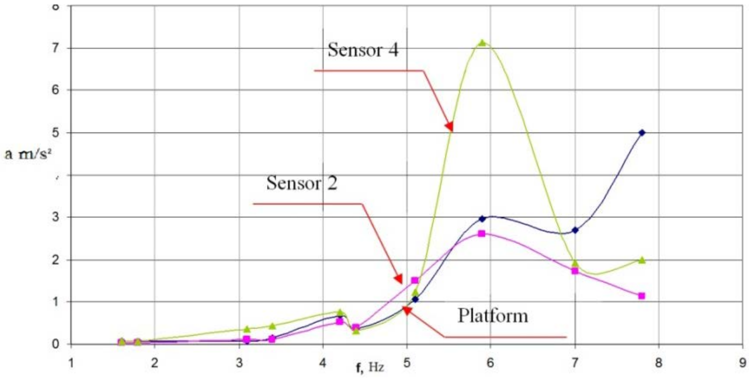

Figure 9. Graphs of the dependence of acceleration on the frequency of vertical oscillations of the system

Graphs of the dependence of the relative acceleration σ_p "system-platform" on the frequency of vertical oscillations are shown in Figure 10. It is noted that the acceleration in the system upper part (sensor 4) exceeds the accelerations in the lower part of the structure (sensor 2) at the same frequency of vertical oscillations.

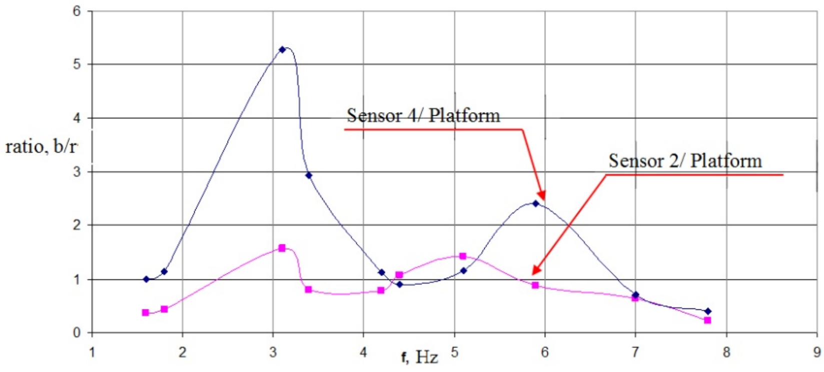

Figure 10. Graphs of the dependence of the relative acceleration σp "system-platform" on the frequency of vertical oscillations

As can be seen in Figure 11, the maximum value of the system displacement at the frequency of horizontal oscillations of the structure was 37 mm at a frequency of 4.3 Hz (sensor 1). The maximum value of the horizontal platform displacement, equal to 15.1 mm, was observed at a system oscillation frequency of 1.7 Hz.

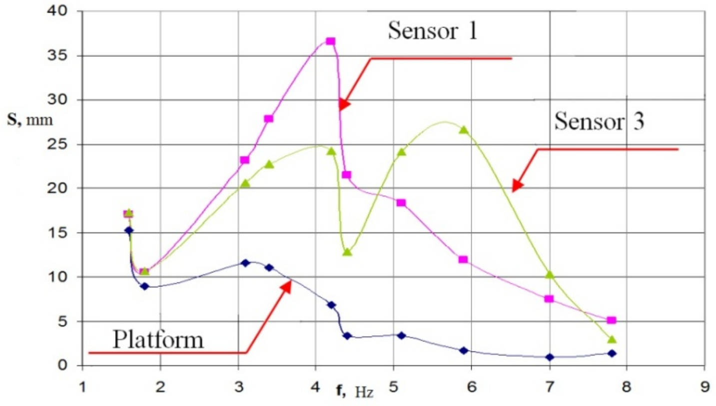

Figure 11. Graphs of the dependence of displacements on the frequency of horizontal system oscillations

The graphs of the dependence of the relative displacement (σ_p) "system-platform" on the horizontal frequency are shown in Figure 12. The maximum movement of the tested structure is marked in its upper part (sensor 3).

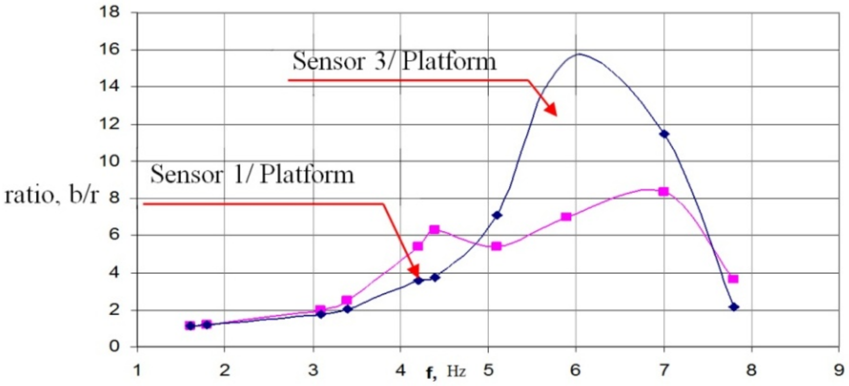

Figure 12. Graphs of the dependence of the relative displacement (σ_p) "system-platform" on the horizontal frequency

The maximum value of moving the system equal to 5.2 mm was fixed by the sensor at a frequency of vertical oscillations corresponding to 5.9 Hz. The maximum displacement value of the platform was 3.0 mm at an oscillation frequency of 5.0 Hz. Maximum movements with vertical oscillations of the structure occur in its upper part (sensor 4) (Figure 13).

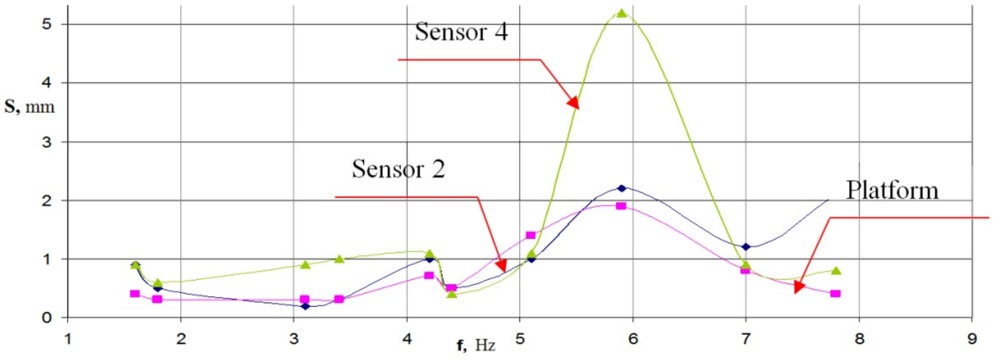

Figure 13. Graphs of the dependence of displacements on the frequency of vertical system oscillations

Graphs of the dependence of the relative displacement (σ_p) "system-platform" on the frequency of vertical oscillations are shown in Figure 14. The maximum displacement of the structure with vertical, as in the case of horizontal oscillations (Figure 12), is marked in its upper part (sensor 4).

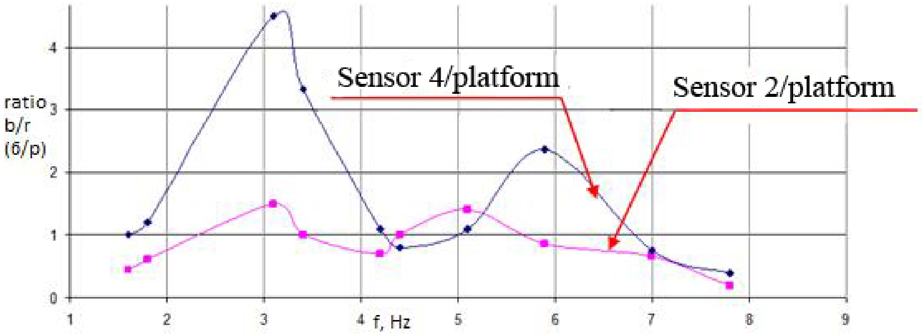

Figure 14. Graphs of the dependence of the relative displacement (σp) "system-platform" on the vertical frequency

At the moment when the natural frequencies of the system oscillations coincided with the forced oscillation frequencies of the vibrating platform, a phenomenon of resonance was observed. The phenomenon of resonance was observed at different stages of loading at a frequency of f = 6.4 ÷ 6.6 Hz. The operational reliability of the system was not affected by resonance.

It should be noted that the developed facade system dampens the vibrations from the dynamic loads effectively due to the features of the structural solution of the toothed junction of the facing with the substructure.

An estimation of HFS with a toothed fastening of the cladding seismic resistance was made on the basis of a comparative analysis of the results of an experimental study of the operation of a structure under dynamic loads with data from similar tests of a traditional system with fastening of facing plates to the guides [22–25, 33].

The generalized test results of the developed and traditional HFS designs are given in Table 1.

Table 1. Test results of the developed and traditional HFS designs

HFS designs	HFS's natural vibration frequency, Hz		HFS's maximum acceleration, m/s^2		HFS's maximum displacement, mm	
	horizontal oscillations	vertical oscillations	horizontal oscillations	vertical oscillations	horizontal oscillations	vertical oscillations
Developed HFS (with toothed fastening of the lining) No damage detected	3÷4	6	37	7	37	5
Traditional HFS (with fastening of facing to guides) Damage detected [24]	5÷6	6	19	7.8	55	5.7

4. Conclusions

It is possible to conclude from the results of an experimental study of the load-bearing capacity of the HFS structure with toothed fastening of the lining of ACP under conditions of dynamic loads:

1. The developed system with toothed units for fastening facing plates is characterized by increased seismic resistance with less material capacity, operational reliability of which has not been disturbed at all stages of dynamic loading in comparison with existing facade systems.

2. As a result of testing, visible defects and damages in the elements of the developed HFS design were not detected in contrast to traditional systems.

3. It is established that the developed HFS well dampens the oscillations from the effect of dynamic loads due to the features of the node-toothed clamping of the cladding, which confirms the possibility of its effective use in areas with seismicity of 7-9 points on the MSK-64 scale.

Taking into account the above mentioned, it can be concluded that the HFS design with the clamping of the lining of ACP has a high load-bearing capacity under conditions of high wind and seismic loads and can be recommended for use in high-rise buildings for all Russian climatic regions. This will expand the area of effective use of hinged facade systems with aluminum composite panels.

References

1. Ventiliruemye fasady. Mify i realnost [Ventilated facades. Myths and Reality]. *Tehnologii stroitel'stva.* 2004. No. 5. Pp. 4-11. (rus).
2. Vatin N.I., Gorshkov A.S., Rymkevich P.P. Methodology for calculating the recoupment of investments for renovating the facades of existing buildings. *Construction of Unique Buildings and Structures.* 2014. No. 2(17). Pp. 82–106. (rus).
3. Glikin S.M., Kodysh EH.N. Navesnye fasadnye sistemy s ehffektivnoj teploizolyaciej i ventiliruemym vozdushnym zazorom [Hinged facade systems with effective thermal insulation and ventilated air gap]. *Promyshlennoe i grazhdanskoe stroitel'stvo*. 2008. No. 9. Pp. 36–37. (rus).
4. Nemova D.V. Navesnyye ventiliruyemyye fasady: obzor osnovnykh problem [Hinged ventilated facades: an overview of the main problems]. *Magazine of Civil Engineering*. 2010. No. 5. Pp. 7–11. (rus).
5. *Fasadnyye teploizolyatsionnyye sistemy s vozdushnym zazorom. Rekomendatsii po sostavu i soderzhaniyu dokumentov i materialov, pred"yavlyayemykh dlya tekhnicheskoy otsenki prigodnosti produktsii* [Facade thermal insulation systems with air gap. Recommendations on the composition and content of documents and materials required for technical evaluation of the suitability of products]. Moscow. 2004. 59 p. (rus).
6. *Rekomendatsii po proyektirovaniyu navesnykh fasadnykh sistem s ventiliruyemym vozdushnym zazorom dlya novogo stroitel'stva i rekonstruktsii zdaniy* [Recommendations for the design of hinged facade systems with ventilated air gap for new construction and reconstruction of buildings]. M.: Moskomarkhitektura. 2002. 98 p. (rus).
7. Vatin N.I., Gorshkov A.S., Nemova D.V. Energy efficiency of enclosing structures during major overhaul. *Construction of Unique Buildings and Structures.* 2013. No. 3(8). Pp. 1–11. (rus).
8. Gamayunova O., Vatin N. The role of the state and citizens to improve energy efficiency. *Applied Mechanics and Materials.* 2015. Vols. 725–726. Pp. 1493–1498.
9. Perlova E., Karpova S., Rakova X.M., Bondarenko E., Platonova M., Gorshkov A. The architectural concept of the building with low energy consumption. *Applied Mechanics and Materials*. 2015. Vols. 725–726. Pp. 1580–1588.
10. Dagnall M., Window A., Leung A., Thompson D. Analytical assessment of thermal performance of a ventilated glazed facade system. *Proceedings of Building Simulation: 12th Conference of International Building Performance Simulation Association*. Sydney, 2011. Pp. 808–815.
11. Vatin N.I., Gorshkov A.S., Nemova D.V., Staritcyna A.A., Tarasova D.S. The energy-efficient heat insulation thickness for systems of hinged ventilation facades. *Advanced Materials Research*. 2014. No. 941–944. Pp. 905–920.
12. Vatin N., Gorshkov A., Rymkevich P., Nemova D., Tarasova D. Nonstationary thermal conduction through the building envelope. *Applied Mechanics and Materials*. 2014. No. 670–671. Pp. 365–369.
13. Patania F., Gagliano A., Nocera F., Ferlito A., Galesi A. Thermofluid-dynamic analysis of ventilated facades. *Energy and Buildings*. 2010. Vol. 42. Pp. 1148–1155.
14. Suarez C., Joubert P., Molina J.L., Sánchez F.J. Heat transfer and mass flow correlations for ventilated facades. *Energy and Buildings*. 2011. Vol. 43. Pp. 3696–3703.
15. Nizovtsev M.I., Belyi V.T., Sterlygov A.N. The facade system with ventilated channels for thermal insulation of newly constructed and renovated buildings. *Energy and Buildings*. 2014. Vol. 75. Pp. 60–69.
16. Šagát E., Matějka L. Experimental assessment of the

Литература

1. Вентилируемые фасады. Мифы и реальность // Технологии строительства. 2004. № 5. С. 4–11.
2. Ватин Н.И., Горшков А.С., Рымкевич П.П. Методика расчета окупаемости инвестиций по реновации фасадов существующих зданий // Строительство уникальных зданий и сооружений. 2014. № 2(17). С. 82–106.
3. Гликин С.М., Кодыш Э.Н. Навесные фасадные системы с эффективной теплоизоляцией и вентилируемым воздушным зазором // Промышленное и гражданское строительство. 2008. № 9. С. 36–37.
4. Немова Д.В. Навесные вентилируемые фасады: обзор основных проблем // Инженерно-строительный журнал. 2010. № 5. С. 7–11.
5. Фасадные теплоизоляционные системы с воздушным зазором. Рекомендации по составу и содержанию документов и материалов, предъявляемых для технической оценки пригодности продукции. Москва. 2004. 59 с.
6. Рекомендации по проектированию навесных фасадных систем с вентилируемым воздушным зазором для нового строительства и реконструкции зданий. М.: Москомархитектура, 2002. 98 с.
7. Ватин Н.И., Горшков А.С., Немова Д.В. Энергоэффективность ограждающих конструкций при капитальном ремонте // Строительство уникальных зданий и сооружений. 2013. № 3(8). С. 1–11.
8. Gamayunova O., Vatin N. The role of the state and citizens to improve energy efficiency // Applied Mechanics and Materials. 2015. Vols. 725–726. Pp. 1493–1498.
9. Perlova E., Karpova S., Rakova X.M., Bondarenko E., Platonova M., Gorshkov A. The architectural concept of the building with low energy consumption // Applied Mechanics and Materials. 2015. Vols. 725–726. Pp. 1580–1588.
10. Dagnall M., Window A., Leung A., Thompson D. Analytical assessment of thermal performance of a ventilated glazed facade system // Proceedings of Building Simulation: 12th Conference of International Building Performance Simulation Association. Sydney, 2011. Pp. 808–815.
11. Vatin N.I., Gorshkov A.S., Nemova D.V., Staritcyna A.A., Tarasova D.S. The energy-efficient heat insulation thickness for systems of hinged ventilation facades // Advanced Materials Research. 2014. № 941–944. Pp. 905–920.
12. Vatin N., Gorshkov A., Rymkevich P., Nemova D., Tarasova D. Nonstationary thermal conduction through the building envelope // Applied Mechanics and Materials. 2014. № 670–671. Pp. 365–369.
13. Patania F., Gagliano A., Nocera F., Ferlito A., Galesi A. Thermofluid-dynamic analysis of ventilated facades // Energy and Buildings. 2010. Vol. 42. Pp. 1148–1155.
14. Suareza C., Joubertb P., Molinaa J.L., Sánchez F.J. Heat transfer and mass flow correlations for ventilated facades // Energy and Buildings. 2011. Vol. 43. Pp. 3696–3703.
15. Nizovtsev M.I., Belyi V.T., Sterlygov A.N. The facade system with ventilated channels for thermal insulation of newly constructed and renovated buildings // Energy and Buildings. 2014. Vol. 75. Pp. 60–69.
16. Šagát E., Matějka L. Experimental assessment of the influence of wind speed on the airflow and temperatures in the open joint ventilated façade cavity // Applied Mechanics and Materials. 2016. Vol. 835. Pp. 444–449.
17. Šagát E., Matějka L., Pěnčík J. Experimental assessment of the influence of outlet geometry on the airflow and temperatures in the ventilated façade cavity // Applied Mechanics and Materials. 2016. Vol. 824. Pp. 641–648.

influence of wind speed on the airflow and temperatures in the open joint ventilated façade cavity. *Applied Mechanics and Materials*. 2016. Vol. 835. Pp. 444–449.

17. Šagát E., Matějka L., Pěnčík J. Experimental assessment of the influence of outlet geometry on the airflow and temperatures in the ventilated façade cavity. *Applied Mechanics and Materials.* 2016. Vol. 824. Pp. 641–648.
18. Ryabukhina S., Simankina T., Koshkarova M., Sokolovskii N., Ryzhkov O. Combined thermal insulating module of mounted vented facades. *MATEC Web of Conferences.* 2016. Vol. 73. 02005.
19. Peci López F., Jensen R.L., Heiselberg P., Ruiz de Adana Santiago M. Experimental analysis and model validation of an opaque ventilated facade. *Building and Environment*. 2012. Vol. 56. Pp. 265–275.
20. *SP 14.13330.2014. SNiP II-7-81* Stroitelstvo v seysmicheskikh rayonakh* [Russian Set of Rules SP 14.13330.2014. SNiP II-7-81* Construction in seismic regions]. TsNIISK im. V.A. Kucherenko, OAO «NITs «Stroitelstvo». M.: OAO «TsPP», 2014. 126 p.
21. Ajzenberg Ja.M., Akbiev R.T., Smirnov V.I., Chubakov M.Zh. Dinamicheskie ispytanija i sejsmostojkost' navesnyh fasadnyh system [Dynamic testing and seismic stability of hinged facade systems]. *Sejsmostojkoe stroitel'stvo. Bezopasnost' sooruzhenij*. 2008. No. 1. Pp. 13–15. (rus).
22. Granovskij A.V., Haktaev S.S. K voprosu o primenenii fasadnyh teploizoljacionnyh kompozitnyh sistem dlja sten zdanij, vozvodimyh v obychnyh i sejsmoopasnyh regionah Rossii [To the problem of the application of facade heat-insulating composite systems for walls of buildings erected in conventional and seismic regions of Russia]. *Promyshlennoe i grazhdanskoe stroitel'stvo.* 2015. No. 4. Pp. 96–100. (rus).
23. Granovskiy A.V., Kiselev D.A. Eksperimental'nyye issledovaniya raboty ankernogo krepezha pri dinamicheskikh vozdeystviyakh [Experimental studies of the work of anchoring fasteners under dynamic actions]. *Seysmicheskoye stroitel'stvo. Bezopasnost' sooruzheniy.* 2012. No. 1. Pp. 43-45. (rus).
24. *Tekhnicheskiy otchet po rezul'tatam eksperimental'nykh issledovaniy seysmostoykosti konstruktsiy navesnykh ventiliruyemykh fasadnykh sistem «AL-SITI» tipov «AL-SITI» K i «AL-SITI» A.* [Technical report on the results of experimental seismic resistance studies of ventilated facade systems "AL-CITY" types "AL-CITY" K and "AL-CITY" A]. M.: TSNIISK im. V.A. Kucherenko. 2007. 30 p. (rus).
25. Granovskij A.V., Dottuev Z.I., Hasanov T.M. K voprosu o metodike ispytanij i ocenke sejsmostojkosti navesnyx fasadnyx sistem [To the problem of the method of testing and evaluation of seismic resistance of hinged facade systems]. *Promyshlennoe i grazhdanskoe stroitel'stvo*. 2009. No. 10. Pp. 15–17. (rus).
26. Wen Y.K., Kang Y.J. Minimum building life-cycle cost design criteria. II. Applications. *Journal of Structural Engineering New York*. 2001. No. 127(3). Pp. 338–346.
27. Tusnina V.M, Emel'janov A.A., Granovskij A.V. Puti povyshenija sejsmostojkosti ventiliruemyh fasadnyh system [Ways to increase seismic resistance of ventilated facade systems]. *Promyshlennoe i grazhdanskoe stroitel'stvo*. 2014. No. 11. Pp. 63–65. (rus).
28. Tusnina V.M., Emel'janov D.A. Uzlovye soedineniya elementov v nesushhix sistemax navesnyx ventiliruemyx fasadov [Nodal connections of elements in load-bearing systems of hinged ventilated facades]. *Promyshlennoe i grazhdanskoe stroitel'stvo*. 2013. No. 9. Pp. 11–13. (rus).
29. Tusnina V.M., Yemel'yanov D.A. Eksperimental'noye issledovaniye uzlov krepleniya otdelochnykh kasset dlya sistem navesnykh ventiliruyemykh fasadov [Experimental research of the attachment points of finishing cassettes for systems of hinged ventilated facades]. *Promyshlennoye i grazhdanskoye stroitel'stvo*. 2015. No. 3. Pp. 11–13. (rus).

18. Ryabukhina S., Simankina T., Koshkarova M., Sokolovskii N., Ryzhkov O. Combined thermal insulating module of mounted vented facades // MATEC Web of Conferences. 2016. Vol. 73. 02005.
19. Peci López F., Jensen R.L., Heiselberg P., Ruiz de Adana Santiago M. Experimental analysis and model validation of an opaque ventilated facade // Building and Environment. 2012. Vol. 56. Pp. 265–275.
20. СП 14.13330.2014. СНиП II-7-81* Строительство в сейсмических районах / ЦНИИСК им. В.А. Кучеренко, ОАО «НИЦ «Строительство». М.: ОАО «ЦПП», 2014. 126 с.
21. Айзенберг Я.М., Акбиев Р.Т., Смирнов В.И., Чубаков М.Ж. Динамические испытания и сейсмостойкость навесных фасадных систем // Сейсмостойкое строительство. Безопасность сооружений. 2008. № 1. С. 13-15.
22. Грановский А.В., Хактаев С.С. К вопросу о применении фасадных теплоизоляционных композитных систем для стен зданий, возводимых в обычных и сейсмоопасных регионах России // Промышленное и гражданское строительство. 2015. № 4. С. 96–100.
23. Грановский А.В., Киселев Д.А. Экспериментальные исследования работы анкерного крепежа при динамических воздействиях // Сейсмическое строительство. Безопасность сооружений. 2012. № 1. С. 43-45.
24. Технический отчет по результатам экспериментальных исследований сейсмостойкости конструкций навесных вентилируемых фасадных систем «AL-СИТИ» типов «AL-СИТИ» К и «AL-СИТИ» А. М: ЦНИИСК им. В.А. Кучеренко. 2007. 30 с.
25. Грановский А.В., Доттуев З.И., Хасанов Т.М. К вопросу о методике испытаний и оценке сейсмостойкости навесных фасадных систем // Промышленное и гражданское строительство. 2009. № 10. С. 15–17.
26. Wen Y.K., Kang Y.J. Minimum building life-cycle cost design criteria. II. Applications // Journal of Structural Engineering New York. 2001. № 127(3). Pp. 338–346.
27. Туснина В.М, Емельянов А.А., Грановский А.В. Пути повышения сейсмостойкости вентилируемых фасадных систем // Промышленное и гражданское строительство. 2014. № 11. С. 63–65.
28. Туснина В.М., Емельянов Д.А. Узловые соединения элементов в несущих системах навесных вентилируемых фасадов // Промышленное и гражданское строительство. 2013. № 9. С. 11–13.
29. Туснина В. М., Емельянов Д.А. Экспериментальное исследование узлов крепления отделочных кассет для систем навесных вентилируемых фасадов // Промышленное и гражданское строительство. 2015. № 3. С. 46–49.
30. Tusnina V.M., Emelyanov D.A., Tusnina O.A. Design of a Suspended Ventilated Fasade with composite Fasing // Applied Mechanics and Materials. 2014. Vols. 578-579. Pp. 226–229.
31. Туснина В.М., Емельянов Д.А. К вопросу расчёта и проектирования навесных вентилируемых фасадных систем // Промышленное и гражданское строительство. 2016. № 3. С. 38–42.
32. MSK-64. Шкала сейсмической интенсивности MSK. 1964.
33. СТО 44416204-012-2013. Элементы облицовочные навесных фасадных систем с воздушным зазором и детали их крепления. Метод определения несущей способности по результатам лабораторных испытаний. Москва. ФАУ «ФЦС». ЦНИИПСК им. Н.П. Мельникова. 2013. 30 с.

Tusnina V.M., Emelianov D.A. The seismic stability of facade system with facing by composite panels. *Magazine of Civil Engineering*. 2018. No. 4. Pp. 62–72. doi: 10.18720/MCE.80.6.

30. Tusnina V.M., Emelyanov D.A., Tusnina O.A.. Design of a Suspended Ventilated Fasade with composite Fasing. *Applied Mechanics and Materials*. 2014. Vols. 578-579. Pp. 226–229.
31. Tusnina V.M., Yemel'yanov D.A. K voprosu raschota i proyektirovaniya navesnykh ventiliruyemykh fasadnykh system [To the question of calculation and design of hinged ventilated facade systems]. *Promyshlennoye i grazhdanskoye stroitel'stvo*. 2016. No. 3. Pp. 38–42. (rus).
32. *MSK-64.* Shkala seysmicheskoy intensivnosti MSK [MSK-64. Scale of seismic intensity MSK].1964.
33. *STO 44416204-012-2013.* Elementy oblitsovochnyye navesnykh fasadnykh sistem s vozdushnym zazorom i detali ikh krepleniya. Metod opredeleniya nesushchey sposobnosti po rezul'tatam laboratornykh ispytaniy [Russian technical standard of the organization STO 44416204-012-2013. Elements facing facade systems with an air gap and details of their fastening. The method of determining the load-bearing capacity by the results of laboratory tests]. Moscow. FAI "FCS". TsNIIPSK them. N.P. Melnikov. 2013. 30 p. (rus).

Valentina Tusnina,*
+7(916)510-72-24; valmalaz@mail.ru

Denis Emelianov,
+7(903)751-75-29; snegiri_emelianov@mail.ru

Валентина Матвеевна Туснина,*
+7(916)510-72-24; эл. почта: valmalaz@mail.ru

Денис Андреевич Емельянов,
+7(903)751-75-29;
эл. почта: snegiri_emelianov@mail.ru