IOP Conference Series: Materials Science and Engineering

PAPER • **OPEN ACCESS**

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To cite this article: A S Antonov *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **570** 012006

IOP Conf. Series: Materials Science and Engineering **570** (2019) 012006 doi:10.1088/1757-899X/570/1/012006

Study of the real work of constructions of translucent facade systems

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Abstract. The issues of actual operation of structures, the most common stay-brace-and-cross-beam translucent facade systems used in the fencing of buildings and structures are studied, taking into account the spatial rigidity of the elements of the system. The existing building codes of the Russian Federation, in the absence of specialized methods for calculating such systems, offer static calculation schemes for the supporting frame without taking into account the other elements of the system, including the translucent modules themselves, which do not take into account the behavior of the actual structure and often leads to an increase in the cross section of the bearing elements and their value. Thus, in order to study the actual work and bearing capacity of the structures of translucent facade systems, numerical and experimental tests were carried out with modeling of the actual operating conditions, studies were performed for a fragment of the facade system, the stress-strain state of the system structures was analyzed taking into account their spatial work. Results were obtained on the actual operation of the structures, and behavioral features were revealed under the action of critical forces, which must be taken into account when further calculating and designing such systems.

1. Introduction

In recent years, facade systems, the structures of which include translucent elements, have become widespread in the Russian Federation as enclosing structures of buildings and structures. The most common of these are standard stay-brace-and-cross-beam systems. These systems are a frame in the form of, usually, aluminum cross-sections, on which translucent fences are installed, with fastening to bearing brackets, which in turn are anchored to the building foundation. General view and examples of the use of such facade systems are presented in figures 1 and 2.

Figure 1. Fragment of the facade using the stay-and-cross-beam system. YAWAL FA 50N HI (Poland)

Figure 2. Fragment of the stay-and-cross-beam system

The main part of research in the field of translucent façade structures is aimed at studying the energy efficiency of these systems, however, when designing and performing static calculations at the design documentation development stage, there is a problem of correctness of using calculation methods with standardized calculation schemes in albums of technical solutions of manufacturers that do not take into account the specifics of work real design. Thus, in order to study the real work and determine the stress-strain state of the structural elements of translucent facade systems, it is necessary to carry out numerical and experimental tests with simulation of the actual operating conditions and taking into account the spatial work of the system elements to obtain results on the actual operation of the structures, to identify behavioral features under the action of critical forces that need to be considered in the further calculation and design of such systems.

2. Numerical studies

2.1. Numerical studies using existing calculation methods

Static calculations of the stay-brace-and-cross-beam of facade systems according to the existing building codes and methods of calculation consist of the separation of the supporting frame from the enclosing structures themselves. In order to determine the stress-strain state of the supporting structures of the stay-brace-and-cross-beam facade system, a fragment of the facade of the building with the most common dimensions and cross-sections of the supporting frame elements was selected. The fragment represents stay-braces - vertical load-bearing elements of the system from aluminum alloys, cross-beams - horizontal load-bearing elements of the system from aluminum alloys, these elements of the system perceive loads, from translucent modules installed on them, loads from wind and icy influences, efforts from loads from the supporting frame are transmitted to the construction base, usually, the ends of the monolithic reinforced concrete floor slabs of the building, through the supporting brackets made of aluminum alloys or steel.

The design scheme of a fragment of the facade system is modeled in the SCAD-Office, the skeleton scheme is set as auxiliary bars with hinged fastening at the edges, both for vertical stay-braces (detachment by bearing brackets mounted on a building foundation) and for horizontal auxiliary bars cross-beams (auxiliary bars cross-beams are hinged to the continuous rod of the bars). A simplified design of the auxiliary bar stay-brace is shown in Figure 3, the design diagram of the investigated fragment of the facade system is shown in Figure 4.

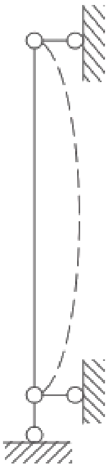


Figure 3. Simplified design of auxiliary bar-stay-brace

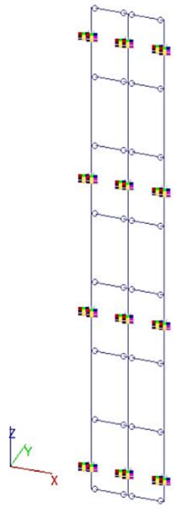
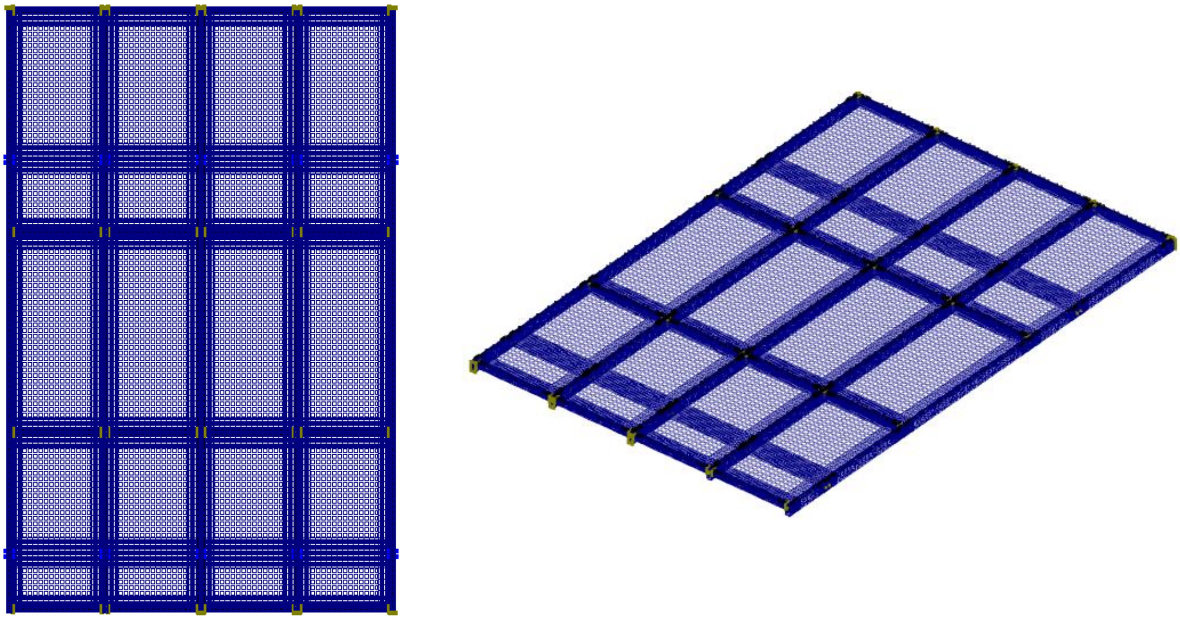


Figure 4. The design scheme of the studied fragment of the facade system

The elements of the auxiliary bar of the system are given appropriate stiffness and fixation. To the design scheme, constant loads from the own weight of the supporting frame were taken into account, which are taken into account by the software package, from the weight of translucent modules and temporary loads from wind and ice effects. The calculation was made on the first and second groups of limit states, as well as on the design requirements for these structures. According to the results of the calculation, a picture of the stress-strain state of the adopted sections of the supporting frame elements was obtained, so the stress values in the auxiliary bar elements — stay-braces, the auxiliary bar — cross-beams and bearing brackets do not exceed the design resistances of the materials of the products, the maximum deflections do not exceed the maximum allowable. However, the values of the adopted sections of the auxiliary bar - stay-brace do not meet the design requirements of the flexibility conditions in the glazing plane of the facade, which is unacceptable for further safe operation. To fulfill the requirements of the conditions of flexibility, measures are needed to detach the elements of the auxiliary bar - stay-brace, which is unacceptable in panoramic glazing, since the aesthetic qualities of the facade of the building are violated, or an increase in the cross-section of the auxiliary bar - stay-brace is necessary, which is also not the best solution, since this decision will lead to a significant increase in the cost of the entire facade of the building. The solution to this problem may be taking into account the remaining elements of the facade system in the design model, including the translucent modules themselves and the nodes from the junction with the supporting frame elements. Consideration of this issue is presented in subsection 2.2 of this article.

2.2. Numerical studies taking into account the spatial work of elements of the facade system

In order to determine the bearing capacity and deformability of the structures of the system of translucent facades, taking into account the spatial work of all elements of the system, numerical studies were carried out in the LIRA-SAPR software package. A finite element model of a facade system fragment has been created. The joints between the elements are modeled according to their actual stiffness. Nods of the base of the bracket are also modeled - parts of the monolithic reinforced concrete structures of the building frame with the corresponding characteristics, anchors and other structures that affect the operation of the system. Characteristics of materials are set according to the design and actual solutions of the investigated structures. Element materials are assigned in nonlinear formulation. The design scheme of the fragment under study, taking into account the remaining elements of the facade system, is presented in figure 5 (a and b).



(a) (b)

Figure 5. General view of the calculated scheme of the fragment under study with the entered elements that are not taken into account when calculating according to the existing calculation methods.
(a) – top view, (b) – isometry

After the assignment of appropriate materials, stiffness characteristics, hinges and connections, the grid of three-dimensional finite elements of the model is divided. The contact surfaces and zones of greatest probable stresses are additionally detailed by a grid of finite elements of a smaller size. To the design scheme, constant loads from the own weight of the fragment structures were taken into account by the program complex, as well as temporary loads from wind and ice effects.

According to the results of calculations, a picture of the stress-strain state of the system structures was obtained, the values of stresses and strains did not exceed the maximum permissible values. In order to establish disk stiffness and determine areas of buckling, taking into account the work of the other elements of the system, additional calculations were made with application of single loads to obtain single movements reflecting the spatial work of facade systems of this type, as well as calculations with application of loads whose values are equal to the critical force for constructions of racks taking into account the spatial work of the fragment. The values of the critical force for each of the uprights were calculated on the basis of calculations of total and local stability, taken into account in the LIRA-SAPR software package. According to the results of the calculations, the zone of the most probable loss of stability of the fragment is determined - from the fastening by the bracket to the upper free end of the extreme stay-brace. Loss of stability stay-brace without the inclusion of the remaining elements of the system (single stay-brace) has a zone of total loss of stability in the middle of the span between the brackets in the glazing plane due to insufficient flexibility of the cross-section of the stay-brace. The values of the critical force for the last stay-brace, taking into account the inclusion of the remaining elements of the system, are 1500 kg, which is more than three times higher than the values of the critical force when calculating without including the other elements, i.e. single stay-brace. The results of determining the critical force, zones of instability and the overall stress-strain state are presented below in figures 6-7.

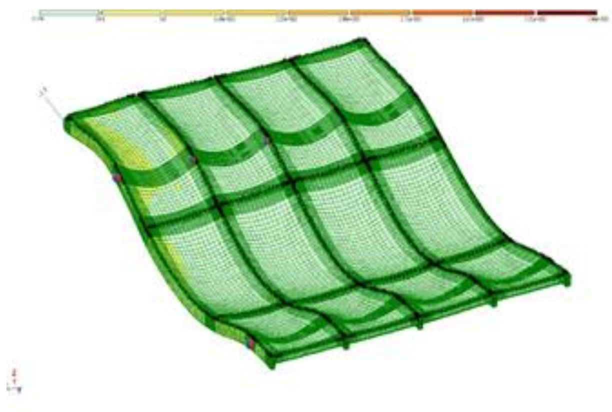


Figure 6. Mosaic of equivalent stresses under the action of the critical force on the last auxiliary bar - stay-brace. General view with glazing

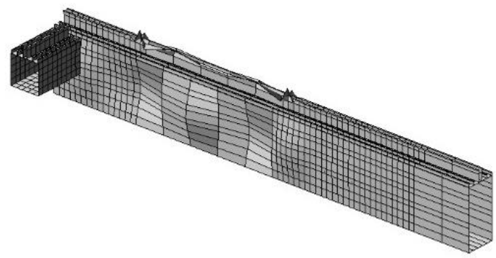


Figure 7. The form of loss of stability of the last auxiliary bar area - stay-brace under the action of critical force

According to the results of numerical studies of the structure of a fragment of a translucent facade system, taking into account the spatial work of all elements of the system, a picture of the stress-strain state of the system elements was obtained, the values of stresses and strains do not exceed the maximum allowable. According to the results of additional studies, the zone of the most probable loss of stability of the fragment was determined - from fastening with a bracket to the upper free end of the last stay-brace. Loss of stability of the stay-brace without the inclusion of the rest of the system elements (single stay-brace) has a zone of total loss of stability in the middle of the span between the brackets in the glazing plane due to insufficient flexibility of the cross-section of the stay-brace. The value of the critical force for last stay-brace is determined taking into account the inclusion of the rest of the system's elements, which is 1500 kg, which is more than three times higher than the values of the critical force when calculating without including the other elements, i.e. single stay-brace.

Thus, when other elements of the system are included in the work, the form of loss of stability of the elements of stay-brace changes, to determine the actual form of loss of stability (in the plane or from the glazing plane) it is necessary to conduct experimental studies in real conditions of operation of this system. With the help of the conducted numerical studies, the picture of the stress-strain state of the system elements was determined for their further control during field tests.

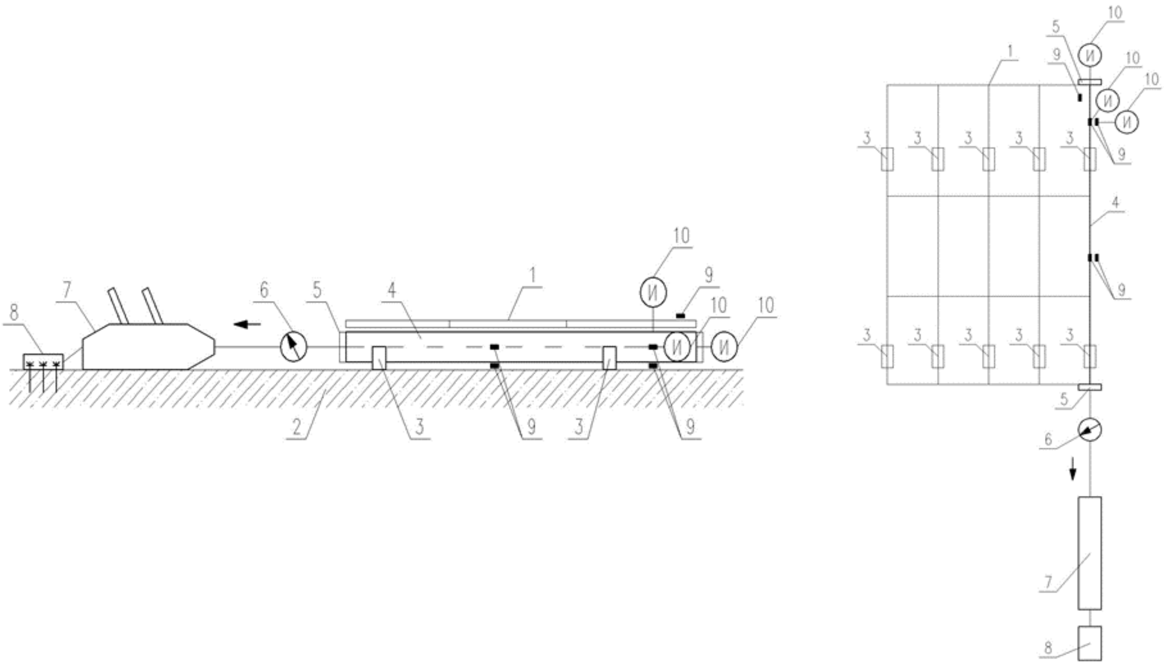
3. Experimental studies

3.1. Methods of testing a fragment of the facade system

To determine the actual bearing capacity, deformability and determine the form of the loss of stability of the stay-brace fragment of the system of translucent facades, experimental studies were conducted. Tests of a fragment of the facade system were carried out in laboratory conditions with the observance of all the parameters of the same design and actually installed at construction sites. A technique has been developed for testing a facade fragment for a critical force, determined from the results of numerical studies, applied as a vertical component of the load of its own weight of modules of a translucent facade to the extreme stay-brace fragment.

The test fragment 1 is mounted in the base 2 through the carrier brackets 3 using anchor fastening. The critical force is transmitted to the extreme stay-brace 4 through a specially designed load transfer system 5, which uniformly transfers the load on the stay-brace to the center of gravity, taking into account the remaining elements of the system fragment. The magnitude of the load is fixed by an electronic dynamometer 6 installed in the circuit. The direction of the force generated by the power winch 7, rigidly fixed to the reinforced concrete base with an anchor 8, is shown in the diagram. The load on a fragment of the facade system was supplied by steps constituting $N \approx 1/10–1/20$ of the

calculated critical force. When testing loading was carried out step by step with measurement at each step of:
- tensioning with strain gauges 9, installed on the stay-brace and the double-glazed window in the places of the highest rated voltages with the loss of stability, through an automated block of hardware and software measuring instruments;
- movements using linear displacement measuring instruments (three hour-type indicators 10 installed in the areas of calculated buckling and in the area of maximum calculated movements). The scheme of the test bench of the facade system fragment is presented in figure 8 (a and b).



(a) (b)

Figure 8. General view of the test bench of a fragment of the facade system.
(a) – side view, (b) – top view

General view of the test bench of the system fragment is presented in figures 9-12.

Figure 9. General view of the tested fragment of the facade system

Figure 10. The area of calculated buckling of a fragment of the facade system. Installed strain gauges and dial gauges

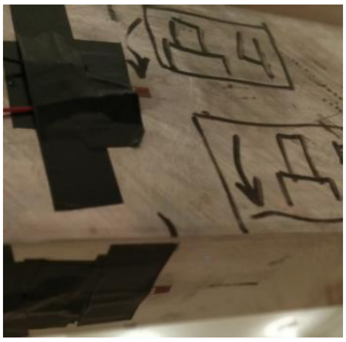


Figure 11. D4 and D5 strain gauges installed on the auxiliary bar stay-brace in the area of the calculated buckling under the action of the critical force without taking into account the work of the other elements

Figure 12. Automated block of hardware and software measurement

3.2. Test results of a facade system fragment by stresses and strains

According to the test results, the values of stresses from strain gauges D1-D5 installed on a fragment of the facade system, and the values of deflections and movements of the stay-brace fragment of the facade system according to the readings of hour-type indicators under the effect of the calculated critical force were obtained. The readings of the D2 and D3 sensors installed in the zone of calculated loss of stability of the auxiliary bar - stay-brace begin to differ significantly when approaching the critical force, which is a sign of the beginning of buckling, similar to indications of indicators No. 1 and No. 2 installed in the zone of calculated loss of stability auxiliary bar - stay-brace. The values for sensor D3 and indicator No. 1 installed on the lower and upper surfaces of the stay-brace, respectively, are higher, therefore, stability is lost from the glazing plane. Graphs of stress and deflection versus load are presented in figures 13 and 14.

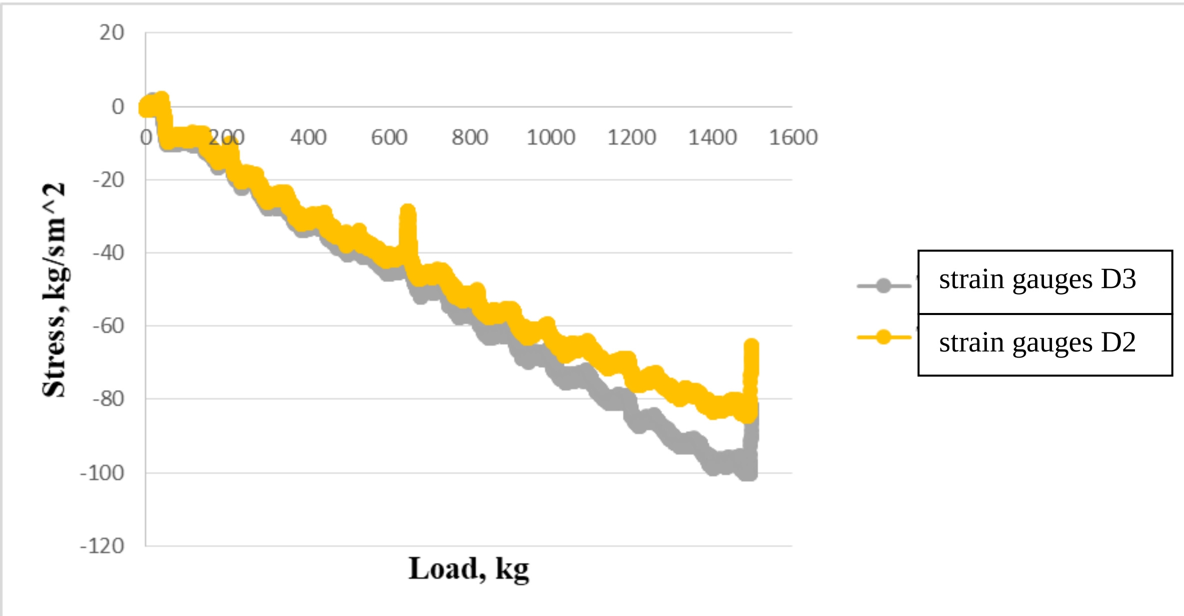


Figure 13. Stress measurement results for strain gauges D2 and D3 in the area of the calculated buckling of the auxiliary bar - stay-brace fragment of the facade system. Graph of stress versus load.

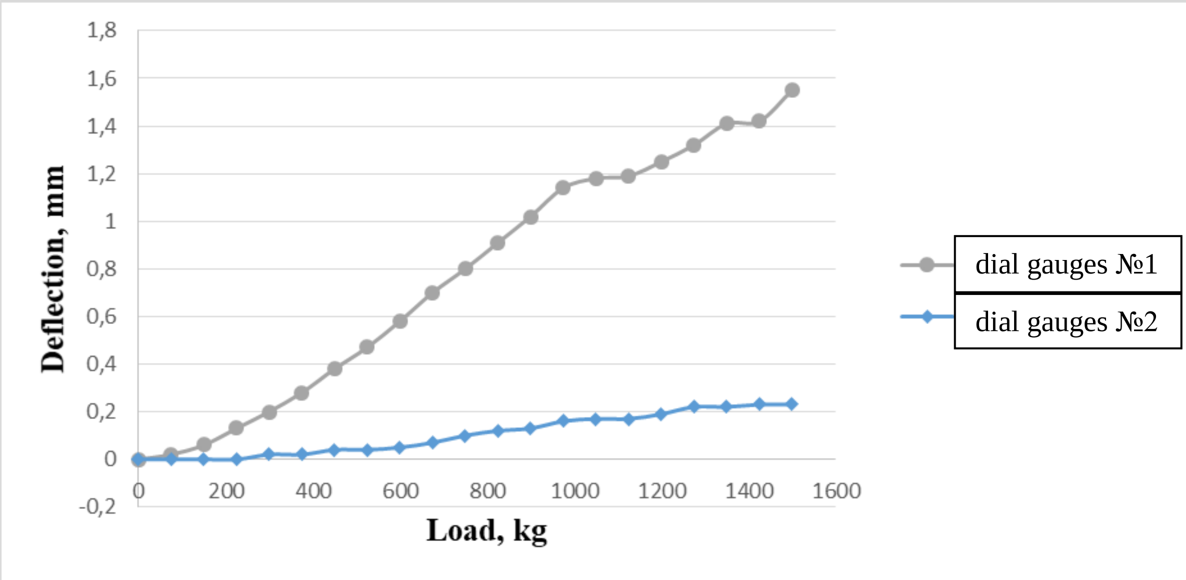


Figure 14. Measurements of auxiliary bar deflection - stay-brace of a facade system fragment using dial gauges No. 1 and No. 2, installed on the upper and side surfaces of the area of calculated buckling, respectively. Deflection versus load graph

4. Conclusion

According to the results of numerical and experimental studies of the structure of a stay-brace-and-cross-beam facade system with translucent modules, with and without spatial work of all elements of the system, a picture of the stress-strain state was obtained, the values of stresses, deflections and displacements were recorded. The actual picture of the stress-strain state was obtained and the actual shape of the stability loss of the stand of a fragment of the facade system under the action of the calculated critical force was established. Thus, it was experimentally established that the actual zone of buckling coincides with the calculated one and ranges from fastening with a bracket to the upper free end of the last auxiliary bar - stay-brace. Loss of stability of the stay-brace, assuming the absence of disk stiffness of a fragment of the facade system, i.e. without the remaining elements of the system (single stay-brace), assumed in the mid-span zone between the brackets in the glazing plane, were not observed due to insufficient flexibility of the cross-section of the stay-brace. The actual loss of stability according to the indications of strain gauges and dial gauges comes from the plane of glazing of the fragment. Therefore, the condition of insufficient flexibility in the glazing plane of the stay-braces of this facade system, provided that the remaining elements of the system are included in the work, is not decisive when performing static calculations of such systems. This requirement can be neglected, if additional numerical and experimental studies for each individual technical solution are made, since the existing methods for calculating such facade systems in the Russian Federation do not have clear requirements and standards.

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