EXPERIMENTAL STUDIES OF SEISMIC RESISTANCE OF TRANSLUCENT FACADE STRUCTURES

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Abstract

The results of experimental studies on the assessment of seismic resistance of hinged facade translucent systems, glass windows and glass panels are presented. The tests were carried out on special stands. When assessing the seismic resistance of facade translucent systems, a two-component pendulum-type vibration platform was used. During dynamic tests of glass windows and glass panels, a stand was used, for the excitation of vibrations of which a system consisting of dynamic hydraulic jacks was used. During the tests, the amplitude-frequency characteristics of dynamic effects varied in the range from 1.0 to 25.0 Hz with the amplitude of vibrations of the vibration platform up to 70 mm in the horizontal direction and 12.8 mm in the vertical direction. The values of accelerations of the vibration platform and dynamic jacks at the specified amplitude-frequency characteristics varied in the range from 0.2 to 5.0 m/s² in the horizontal direction and from 0.1 to 2.0 m/s² in the vertical direction. The behavior of glass panels under dynamic impact is modeled. It has been established that the use of glass partitions wall made of tempered Triplex glass with a thickness of at least t = 18 mm using a strengthening film of the TROSIFOL brand makes it possible to exclude the collapse of the structure of glass panels during the destruction of glass. The analysis of the results of experimental studies on the assessment of seismic resistance and injury safety of glass panels under dynamic loads simulating seismic impacts with an intensity of 7-9 points on the MSK-64 scale is carried out. The necessity of developing special regulatory documents is indicated.

Keywords: translucent structures, dynamic tests, vibration platform.

I. Introduction

The dynamic development of the building materials industry and socio-cultural traditions of the twentieth century contributed to the creation of a new type of respectable buildings with visually weightless, partially or completely transparent facade envelopes. There are many problems that give rise to disagreements among professionals all over the world regarding the design and architecture of glass facades, as well as the physical, mechanical and strength characteristics of the glass used and the fencing system as a whole. There was a need to develop methods for calculating and designing light spatial outer shells made of glass, which are fundamentally different from the previously used standard enclosing facade structures. The American idea of a light facade glazing suspended from the outside of the supporting frame of the building radically changed not only the general technological trends in the production of enclosing structures, but also laid the foundation for a new theory of designing translucent building systems. The results of research by foreign experts have shown that the low reliability of glass exterior enclosing structures in terms of ensuring their reliable trouble-free operation is associated with the perception of both the wind load, its pulsating component and the resulting shock effects from various external elements during a hurricane, and the high amplitude of vibrations of the upper floors of the building during earthquakes. In the Norms of the USA, Canada, Australia, China and Hong Kong, the wind load on the glazing of buildings with a height of 18 to 500 m is considered as the main destructive factor arising from the cyclic application of the load. In Russia, the methodology for determining the magnitude of the design loads on glass facades is based on the instructions of the Norms [1]. In Europe, strength calculations of translucent structures are carried out according to DIN Standards [2,3]. In Russia, recommendations are currently used in the design of hinged translucent facade structures [4,5].

The situation on the Russian market of translucent facade aluminum structures and the forecast of the general situation of the development of this market are set out in [6]. According to these studies, the market volume of facade translucent aluminum structures in 2017 amounted to 56999 tons.

The use of facade translucent aluminum structures in seismic areas is hindered by the lack of experimental studies. The analysis of the state of the regulatory framework for facade systems in Russia and abroad was carried out in the work of St. Petersburg scientists [7].

The methodology of testing translucent facade structures for the action of static and dynamic loads is currently not worked out, which does not allow us to evaluate the results of tests of various systems performed in different research centers from one position. In Russia, the design systems of the vibration platform are conservative harmonic oscillators, with the help of which only a simple harmonic (sinusoidal) oscillation can be realized. A correct dynamic test simulating a particular seismic impact is possible only if a specific accelerogram necessary for the researcher is set during the testing process.

II. Experimental setup and realization of the test

1. Experimental studies of glass facades

Let's analyze the existing methods in Russia and Europe for determining the calculated values of wind load. According to SP [1], the normative value of the average component of the main wind load is determined by the formula:

$$W_m = W_0 \times \kappa(Z) \times c$$

According to DIN [2,3], the magnitude of the hurricane wind pressure $q_{hu.}$ (analogous to W_m) and the velocity $V_{hu.}$ determined by the formula:

$$q_{hu.}(Z) = 2.6 \times q_{ref}\ (Z/10)^{0.19};$$

$$V_{hu.}(Z) = 1.61 \times V_{ref}\ (Z/10)^{0.095},$$

where:

q_{ref} (kN/m^2) is the standard value of wind pressure, analogous to W_m;

V_{ref} (m/s) – wind speed at a height of 10 m from the earth's surface.

The calculation analysis shows that in Russian Standards, the value of the normative value of wind pressure when calculating glass windows is underestimated in comparison with foreign Standards.

At the first stage of dynamic testing of translucent facades for the effect of loads simulating seismic impacts with an intensity of 7-9 points on the MSK-64 scale [8] were carried out on a two-component pendulum-type vibration platform (Figure 1).

In accordance with the Test Program, an enclosing translucent structure designed to provide thermal insulation of premises and their natural illumination was tested. A system in the form of an anti-aircraft lamp was used for the coating (Figure 2).

For the glazing of anti-aircraft lanterns, a 32 mm thick laminated glass мulti – layered block SGLam was used consisting of two (triplex) glasses bonded together and a 6 mm thick SGTempM1 tempered glass covered with a tape. In case of destruction of double-glazed windows during an earthquake, glass fragments remain glued to the tape, which prevents injury to people. Double-glazed windows without triplex with two tempered glasses of the SGTempM1 brand were used on the facade panels. The supporting elements of the glass-transparent structures were made of aluminum alloy. During the tests, 33 modes of dynamic loading of the vibration platform with different amplitude-frequency parameters were performed. According to vibration tests, the amplitude-frequency characteristics of the tested fragments were determined for specific loading levels.

Fig. 1: *Pendulum type vibration platform*

Fig. 2: *Glass facade mounted on a vibration platform*

2. Experimental studies of stained glass and glass partitions wall

At the second stage of the tests, experimental studies of the seismic resistance of the construction of fragments of glass windows and glass walls were carried out. The following elements were used as glass panels for stained glass windows and glass partitions wall:

- all-glass partitions made of tempered non-traumatic glass with a thickness of 10 mm (system 1 - figure 3);
- fire-fighting glass partitions of the EIW(S)90 brand (system 3 - Figure 3);
- glass partitions wall on a spider system and a 10 mm thick tempered glass clamping profile (system 2 - figure 3);
- stained glass systems made of tempered glass with a thickness of 8 mm (system 6 - figure 3);

- office partitions wall systems with double or single tempered non-traumatic glass (system 4 - figure 4);
- stained glass systems with a tempered glass block with a thickness of no more than 68 mm (system 5 - figure 4);
- glass partitions wall on a spider system made of triplex glass with a thickness of at least 18 mm (tempered glass with a thickness of 8 mm + 4 layers of a strengthening tape of the TROSIFOL brand (or equivalent) + tempered glass with a thickness of 8 mm (system 7 - figure 4).

Fig. 3: *Fragments of the stand (systems 1, 3, 2, 6)*

Fig. 4: *Fragments of the stand (systems 4, 5, 7)*

Special dynamic equipment and measuring instruments were used to conduct dynamic tests of stained glass and glass panels. The test stand included the following elements:

- metal stand for fixing glass windows and glass panels;
- rolling supports with a load capacity of 60 kN;
- dynamic hydraulic cylinders of the MTS brand (Figure 5), designed to create a dynamic impact with different acceleration at each stage of loading from 0.2 m/s^2 to 4

m/s^2 with a frequency from 1 to 50 Hz. The amplitude of the displacement of the hydraulic cylinder rod varied from ± 50 to ± 250 mm, the maximum force under dynamic action was ± 800 kN. The rod movement was monitored using an LVDT type displacement sensor;

- 2 steel stops that are not connected to the power frame and ensure the transfer of dynamic load from hydraulic cylinders to a metal stand (Figure 6);
- measuring equipment:
  - accelerometers are single- and triaxial, allowing to determine the magnitude of accelerations with a data acquisition frequency of up to 4000 Hz;
  - NI PXIe-1082 equipment package with NI PXI-4496 modules (for recording accelerometer data) and NI PXIE-4330 (for register and recording data from strain gages);
  - digital controller MT Flux Test 60, designed to control dynamic hydraulic cylinders with the ability to control and change the parameters of their operation during the testing process.

The level of dynamic impact was set in accordance with the Test Program and included the following stages with acceleration values: a_1 = 1.0 m/s^2, a_2 = 2.0 m/s^2 and a_3 = 4.0 m/s^2.

Fig. 5: *Location of hydraulic cylinders relative to the stand*

At each stage of the tests, the frequency spectrum of the effects varied in the range from 0.5 to 22.63 Hz. The duration of the test at each loading step was up to 40-50 s. The tests were performed at fixed frequencies corresponding to the average geometric frequencies of 1/6-octave bands, in the range up to 22.63 Hz.

Fig. 6: *Steel stops for hydraulic cylinders*

In the process of laboratory dynamic tests of the hinged facade system in the form of glass panel, the following was established.

1. The acceleration of the vibration platform varied in the range from 0.2 to 4.9 m/s² in the horizontal direction and from 0.1 to 1.9 m/s² in the vertical direction.
2. The magnitude of the accelerations installed on the vertical stained-glass windows varied from 0.3 to 5.0 m/s² in the horizontal direction and from 0.1 to 3.3 m/s² in the vertical direction.
3. At the level of the zenith lantern, the acceleration values during dynamic loading of the system varied horizontally in the range from 0.3 to 13.6 m/s².
4. The coefficient of dynamism calculated on the basis of processing the results of dynamic tests was β = 2.8. The forced vibration frequency of the vibration platform varied during the tests from 1.5 to 10.0 Hz, the maximum amplitude of the vibrations was 68.4 mm in the horizontal direction and 12.8 mm in the vertical direction. The maximum oscillation amplitude according to the sensors installed on the zenith lantern was 100.1 mm in the horizontal direction and 20.8 mm in the vertical direction. Figure 7 shows the spectra of peak acceleration values at various points along the height of the system in one of the loading modes. At a frequency of 5 Hz, a resonance was detected.

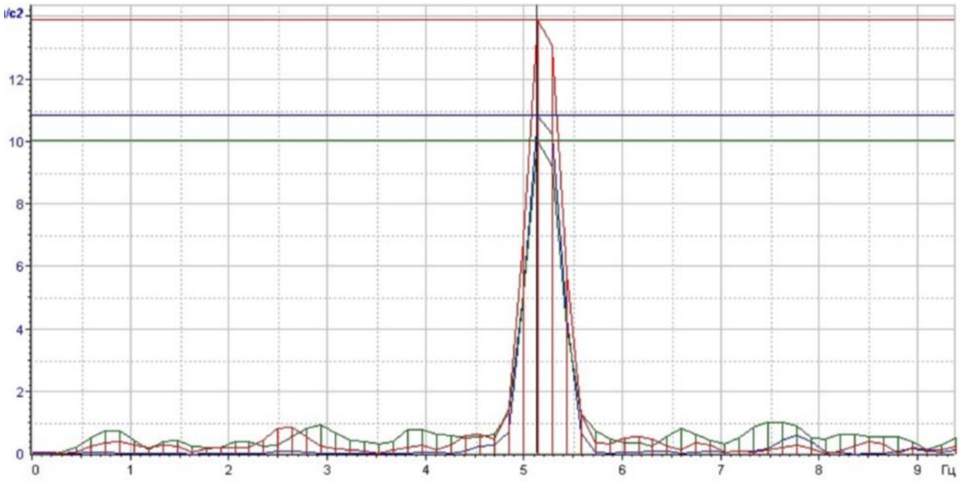

Fig. 7: *Graph of the acceleration spectrum with a frequency change from 0.5 to 9.5 Hz*

III. Analysis of test results

In the process of testing glass windows and glass partitions wall, the following has been established.

1. With a given input dynamic effect corresponding to the acceleration of the base **– 1 m / s² (7 points)**, the maximum value of the acceleration values in the lower and upper zones of the stand was: at the bottom of the stand - 1.98 m/ s², at the top - 6.93 m/s². The maximum coefficient of dynamism under dynamic influences with a change in the frequency spectrum from 0.5 to 22.63 Hz , depending on the type of glass panels , was: for single-chamber partition wall glass - 4.72 at a frequency of 6.35 Hz; for two-chamber stained glass - 3.25 at a frequency of 6.35 Hz; for a fire partition wall - 14.45 at a frequency of 7.13 Hz; for a single-chamber glass partition using a spider fastening of a double-glazed window - 11.77 at a frequency of 7.13 Hz. The resonance effect was established at the frequency of exposure in the range from 2.83 to 5.66 Hz.
2. With a given input dynamic effect corresponding to the acceleration of the base **– 2 m /s² (8 points)**, the maximum value of the acceleration values in the lower and upper zones of the

stand was: at the bottom of the stand – 2.51 m/s², at the top level – 11.74 m/s². The maximum coefficient of dynamism under dynamic influences with a change in the frequency spectrum from 0.5 to 22.63 Hz, depending on the type of glass panels, was: for a single–chamber glass fence - 2.63 at a frequency of 7.13 Hz; for a two-chamber glass screen - 2.7 at a frequency of 7.13 Hz; for a fire partition wall - 19.0 at a frequency of 7.13 Hz; for a single-chamber glass partition wall using a spider fastening of a double-glazed window - 10.3 at a frequency of 8.98 Hz. The resonance effect was established at a frequency of exposure in the range from 2.83 to 5.66 Hz.

3. With a given input dynamic effect corresponding to the acceleration of the base – **4 m /s² (9 points)**, the maximum value of the acceleration values in the lower and upper zones of the stand was: at the bottom of the stand – 4.84 m /s², at the top level – 15.46 m/s². The maximum coefficient of dynamism under dynamic influences with a change in the frequency spectrum from 0.5 to 22.63 Hz, depending on the type of glass panels, was: for a single–chamber glass fence - 2.15 at a frequency of 7.13 Hz; for a two-chamber glass screen - 2.15 at a frequency of 7.13 Hz; for a fire partition - 23.43 at a frequency of 7.13 Hz; for a single-chamber glass fence using a spider fastening of a double-glazed window - 12.87 at a frequency of 4.49 Hz. The resonance effect was established at the frequency of exposure in the range from 2.83 to 5.66 Hz.

In the process of conducting dynamic tests with an impact value corresponding to 9 points, the conditions under which the dynamic impact of the double-glass unit of system 7 on the metal beams of the stand took place were simulated. In the process of repeated dynamic impact, the glass was destroyed without collapsing. The reason for this is the presence of a laminating tape between the layers of the double-glass unit. Figures 8-10 show the process of changing the amplitude of the oscillation of a double-glazed window (over 18 cm) at the moment of impact.

Fig. 8: *Changing the geometry of the glass panel under dynamic influence*

IV. Conclusions

Based on the analysis of the performed dynamic studies and test results with an assessment of the seismic resistance of hinged facade translucent structures, as well as glass windows and glass partitions wall, the following can be noted.

1. During the tests, when the facades of glass windows and glass partitions wall fluctuate, multiple collisions of facing panels with structural elements occur. Due to the high sampling rate and the absence of averaging, peak values of the oscillation amplitudes are recorded at the time of these collisions. These values can reach significant values. The appearance of peak values is due to the peculiarity of the vibration platform and measuring equipment, which should be taken into account when processing test results.
2. It is necessary to develop a regulatory document on the design of translucent structures in earthquake-prone regions. Such a document will allow designers to competently approach the design of translucent systems, taking into account the features of their design solution and a given degree of reliability.

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