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The experimental study of glass multilayer columns using digital image correlation

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ABSTRACT

Purpose: The purpose of the research is to study the deformability of glass multilayer columns at the central compression using digital image correlation. It becomes possible to use the method of digital image correlation for the experimental study of load bearing building structures of glass.

Design/methodology/approach: The approach which has been used to solve the above problems is to conduct an experimental study of glass columns on central compression, in which deformations were measured using digital image correlation.

Findings: The possibility of using load bearing building structures of glass triplex has been discovered. A program of experimental studies was developed. It included the testing of prototype samples on central compression with rigid fastening. On the basis of the obtained results, a graph of dependence of relative deformations on normal tension, graphs of the dependence of the bending of columns on load in different planes, and a modulus of elasticity of triplex glass have been determined.

Research limitations/implications: The lack of a calculation methodology and regulatory documents for designing load bearing building structures of triplex glass increases their cost, since each project is individual and requires the experimental research.

Practical implications: Using the approaches developed in the paper, the method of digital image correlation, which is to measure deformations when testing glass structures on central compression can be applied.

Originality/value: The experimental study is probably the first one in which deformations of glass columns are determined using the method of digital image correlation, so it is new and original. The lack of a calculation methodology and regulatory documents for designing load bearing building structures of triplex glass, increases their cost, since each project is individual and requires the experimental research.

Keywords: Laminated glass column/Glass multilayer column, Digital image correlation, Triplex, Layer glass, Glass column

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

The triplex glass is not very widespread in Ukraine today. It is used in manufacturing floor slabs or small width coverage, partitions, facade glazing or interior elements (tables, stands, etc.). The lack of a calculation methodology and normative documents on the design of load bearing building structures of a glass triplex increases their cost, since each project is individual and requires experimental studies. Triplex is one of the oldest safe glass techniques that has been applied after having analysed numerous road accidents and after a lot of improvements it has begun to be widely used for specific cases. Described with a simple analytical model the behaviour of laminated glass is subjected to compressive loads and to investigate how the mechanical properties of the interlayer [1,2].

During testing of building structures for measuring deformations and displacements, as well as for visual observation of the formation and development of cracks, mechanical devices, strain gauges, optical microscopes, and others are used. For structures made of brittle materials, in particular glass, the fixation of deformability parameters by means of mechanical devices is difficult due to the possibility of their sudden destruction and, accordingly, limited time for the readout immediately before the destruction. Therefore, methods that allow to obtain a complete picture of the deformation of structures up to the time of their destruction are developed within the research process. Today's current issues of improvement of the well-known methods and development of new modern methods and methods for controlling the tension and deformation state of constructions are quite actual. In particular, the methods of measuring the field of deformations allow to obtain important information, both about the mechanical behaviour of materials, and the state of parts and structures. At present, there is a number of experimental methods for measuring the field of deformations: photoconductivity, Moire-interferometry, optical holography, electronic speckle-interferometry, and others. For the study of building structures, the method of digital image correlation (DIC) [3,4] is more effective, which is to determine by means of taking pictures of displacements in the space of the fixed points on the test samples in the process of their deformation. Comparison of photos of stochastically applied contrast points on the surface of structures conducted at different times (at different load), high resolution camera, allows to evaluate deformations of the structures. The advantages of using DIC of high accuracy and quality control of the deformed state of structures are as follows: it is characterized by simplicity, cheapness and accuracy. This method allows to get a complete picture of the deformation of the structure, to reduce the complexity and cover all stages of load until the time of destruction. In this regard, the method of measuring deformations was used within the study of glass columns.

1.1. The analysis of recent studies and publications

One of the main criteria for the usage of material in structures is the availability of design methods and design standards that set the boundary conditions for the material being under load. Since glass is mainly used as a fencing material or finishing element, there are no such techniques and norms for it. It once again confirms the need for their development, as the prospect of using glass in the load bearing structures is highly reasonable. It will provide the emergence of new architectural forms and the introduction of increasingly complex types of structures that will continue to develop engineering and construction craft as such.

The DIC method was applied while testing particular glass samples for determining the tensile strength [14], for the study of glass single- and multilayer plates for dynamic tension [12] and temperature effects [13].

In Ukraine under the guidance of Professor B.G. Demchyna, the study of deformation of glass multilayer columns [6,7] and floor slabs with bending under the action of static load, using DIC has been conducted [3]. The main provisions of the DIC are described in the studies of Ya. Kovalchyk, B. Pena, S. Yoniamy, M. Khelfrika, and others [5-10]. The basic principles of the application of DIC within the experimental studies are considered in the works of V. Berezin, M. Palanka, M. Sutton, T. Proulx, A. Freddie, V. Pickerd, and others [4].

There are no studies related to the tension and deformation state of glass multilayer columns, under the influence of static load using DIC in the analysed publications because of the conducted studies.

According to the analysis of publications [16-28], the following advantages of the DIC method are highlighted as follows: simplicity; relative profitability; wide range of application; low environmental requirements when measured.

2. Description of the approach, work methodology, materials for research, assumptions, experiments etc.

To achieve the goal, the following tasks were formulated:

1) to perform experimental studies of multilayer glass columns under the action of static load;

2) to perform photofixation of the speckle surface of the test specimens when the load is changed;
3) to analyse the obtained images using the tools of the DIC method and image processing functions;
4) to compare the bearing capacity and deformability of glass columns with different number of film layers between glass layers.

For conducting the experimental research, a series of two samples of the brand KS-2.1 and KS-2.2 from a non-pressed sheet of glass M4 [15] (Tab. 1) was made.

The samples are made using triplexing technology, their design is presented in Fig. 1. Between each layer of glass, a polymer film of the EVASAFE brand with the number of one layer for the column of the brand KS-2.1 and two layers for the column of the brand KS-2.2 was put into. After that, the columns were heated at a temperature of 130°C and held for 20-40 minutes in a special chamber.

Experimental specimens were studied as centrally compressed rods with rigidly fixed ends (Fig. 2).

Table 1.
Characteristics of prototype samples

Series	Brand of columns	Section, mm	Height, mm	Number of layers of film between each layer of glass, pc	Thickness of one layer of glass, mm	Characteristics of glass according to DSTU B V.2.7-122: 2009		
						Brand of glass	Compressive strength, MPa	Specific weight, kg/m^3
II	KS-2.1	50x70	1000	1	10	M4	700	2500
	KS-2.2	50x70		2				

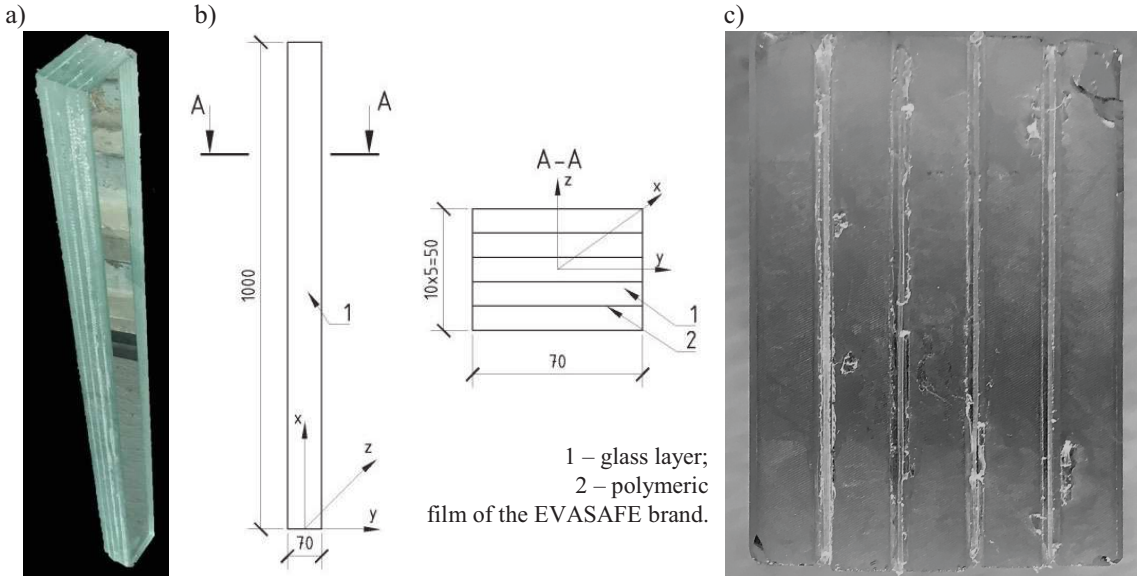


Fig. 1. Multilayer glass column of the II series: a) general view; b) construction; c) general view of the section

The test was conducted on a hydraulic press PG-250. Load N was applied at steps of 25 kN till the time of destruction. The shutter speed at each load level was 10 minutes.

To avoid local shredding and glass destruction in the support areas, column 1 was installed into special metal boxes 3 with 6 mm thick plywood.

For the bending method and the determination of the curvature of the column, six Aistov deflectometers 7 were used, with the scale interval of 0.01 mm, which were placed at three points in height on two mutually perpendicular sides of the columns. For the measurement of longitudinal deformations, five micro-indicators of a clock type 8, with the scale interval of 0.001 mm and a measuring base of 200 mm, were used.

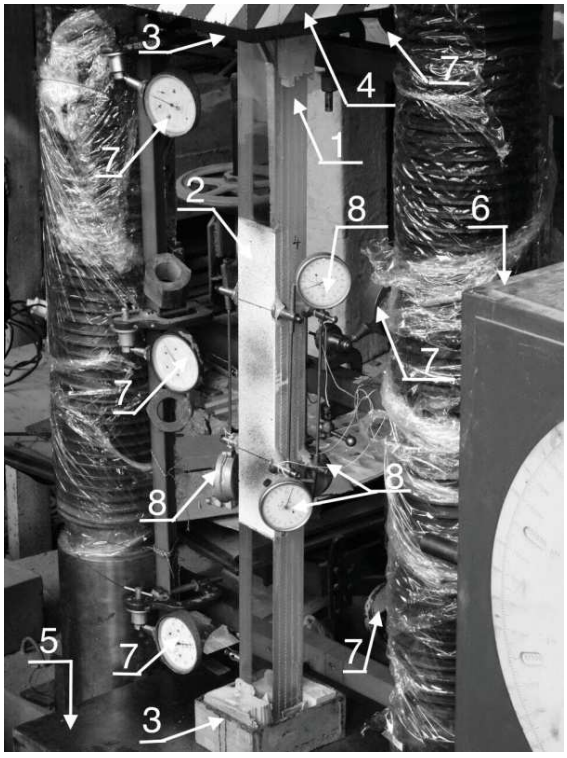


Fig. 2. General view of the test unit: 1 – test column; 2 – speckle-surface for measurement of deformations using DIC; 3 – metal boxes; 4 – fixed traverse of press; 5 – loading traverse of press; 6 – hydraulic press PG-250; 7 – Aistov deflectometer; 8 – clock indicators

To use the DIC method, a speckle-surface 2 was applied to the glue seams of the columns of the speckle-surface 2. For the fixation, a Canon EOS 650D camera was used. It was located on a tripod near the hydraulic press (Fig. 3).

The field for deformation measurements using the DIC consisted of the area occupied by the speckle-surface 2 and the background [11]. There are a lot of ways of creating speckle-surface. In our case, on one of the faces of the column, the speckle surface was applied by spraying a black paint onto a prepared white background (Fig. 4).

To conduct a comparative analysis of the results obtained by the DIC method with mechanical methods, clock-type indicators were used to determine the deformations of glass on the other three faces of the column.

The processing of all obtained images by photo-configuration of the speckle surface during the experiment was carried out in the GOM Correlate software program (GOM mbH, Germany) by analogy [3].

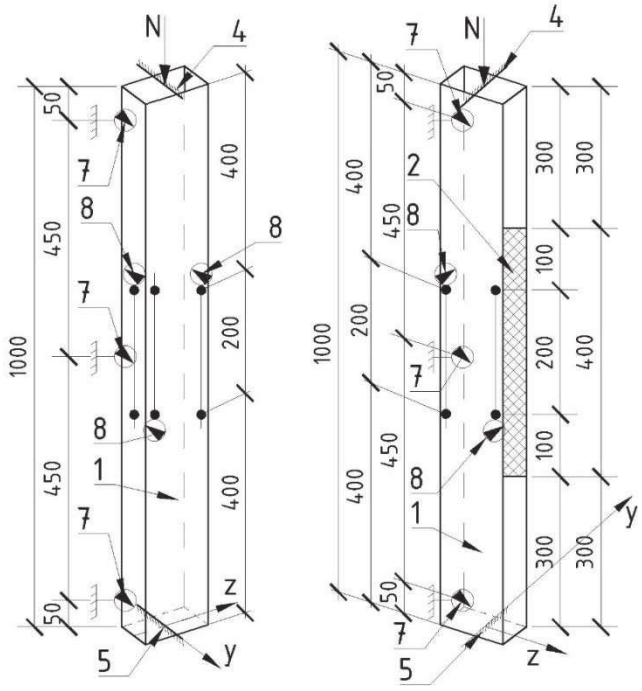


Fig. 3. The layout of the devices: 1 – test column; 2 – speckle-surface for measurement of deformations with the help of DIC; 3 – metal boxes; 4 – fixed traverse of press; 5 – loading traverse of press; 6 – hydraulic press PG-250; 7 – Aistov deflectometer PAO-6; 8 – clock indicators

Fig. 4. General view of speckle surface

3. Description of achieved results of own researches

Determination of relative deformations was performed using 200 mm measuring base in the GOM Correlate software suite. After having analysed the speckle-surface photographs in the process of increasing the load, there was an increase in deformation (with the sign "+" – tension, or "-" – compression) (Fig. 5).

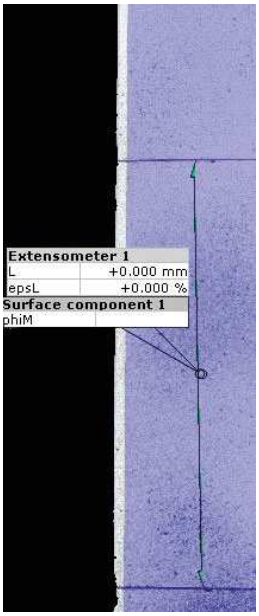


Fig. 5. The interface for displaying absolute and relative deformations in the GOM Correlate program

Comparison of the ranges of relative deformations at different load stages of the studied glass columns for the DIC is presented in Table 2.

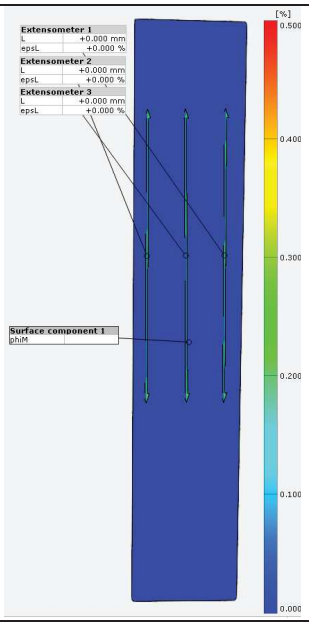
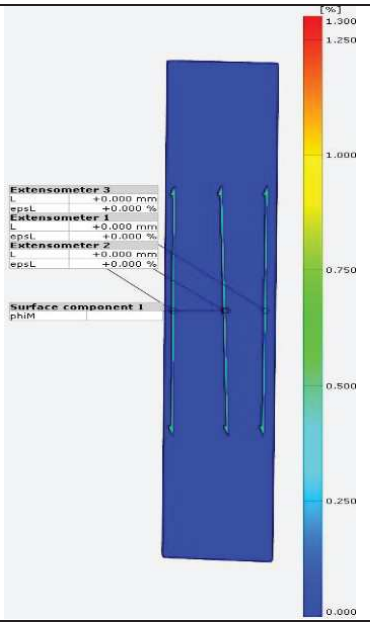
As a result of the research, it was established that the column of the brand KS-2.1 with one layer of the film, was characterized by larger deformations compared with the column of the brand KS-2.2 with two layers of film at identical loads.

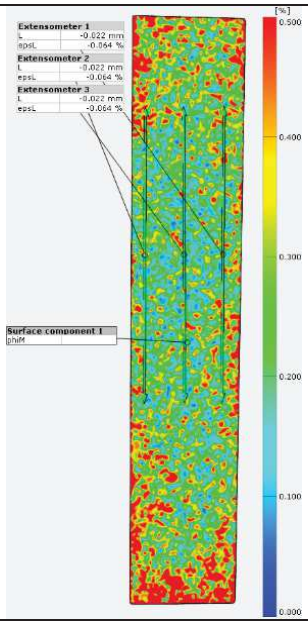
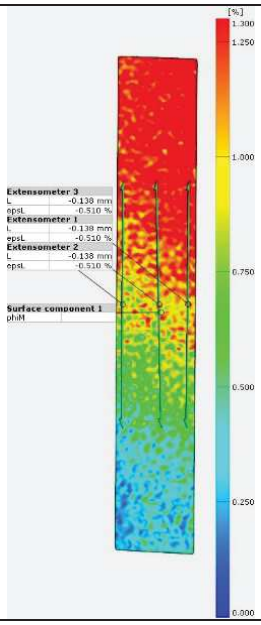
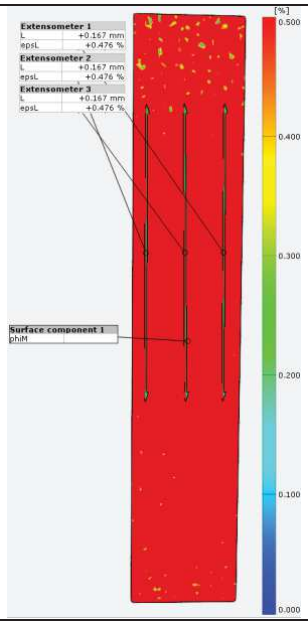
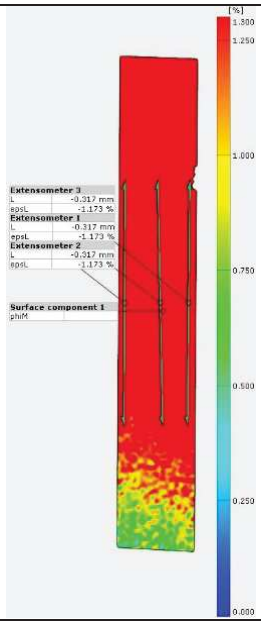
The first shredding of the glass layer of the samples of the II series occurred at a load of Nw = 175 kN in the upper and lower supporting areas (Fig. 6).

The collapse of the prototype samples of the column of the brand KS-2.1 occurred at Nsr = 270 kN, and the columns of the brand KS-2.2 occurred at Nsr = 265 kN. The difference between the results of the test of the prototype samples was 1.85%. The average value of bearing capacity of columns N = 267.5 kN.

The destruction in both columns occurred suddenly in the middle of the height of the column from the cracking of the glass in a layer with a visible bend in the plane perpendicular to the adhesive seams (Fig. 7).

Table 2
Comparison of relative deformations ε according to DIC

Degree of load	Load, kN	Brand of columns / range of relative deformations (%)	
		KS-2.1.	KS-2.2.
1	2	3	4
0	0		
		0.000-1.850	0.000-1.300

1	2	3	4
4	100		
		0.000-1.850	0.000-1.300
9	225		
		0.000-1.850	0.000-1.300

According to the results of experimental studies, the graphs for the bending dependence of the second series of columns in the "XZ" and "XY" planes were constructed depending on the external load (Figs. 8 and 9).

The first cracks on the outer layer of the columns of the brand KS-2.1 and KS-2.2 appeared at a load of Nw = 175 kN. The difference between the destructive load of the Ncr columns and the load at the occurrence of cracks of Nw for the column of the KS-2.1 mark is 35.19%, and for the KS column – 2.2 33.96%. The first cracks in the columns occurred at load of Nw = 0.65 × Ncr.

According to the results of the DIC analysis and the indicators of the clock type, the graphs of dependence of relative deformations on external glass surfaces from normal tension σ = N / A were constructed (Fig. 10).

a) b)

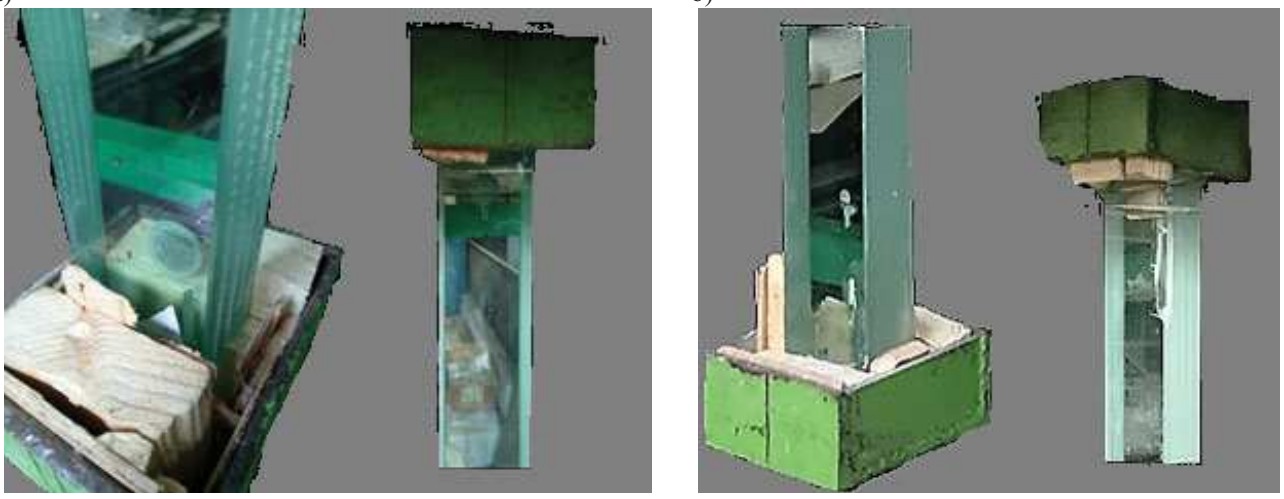


Fig. 6. The nature of the supporting regions of the sample of the II series at load Nw = 175 kN; a) column of the brand KS - 2.1; b) column of the brand KS - 2.2

a) b)

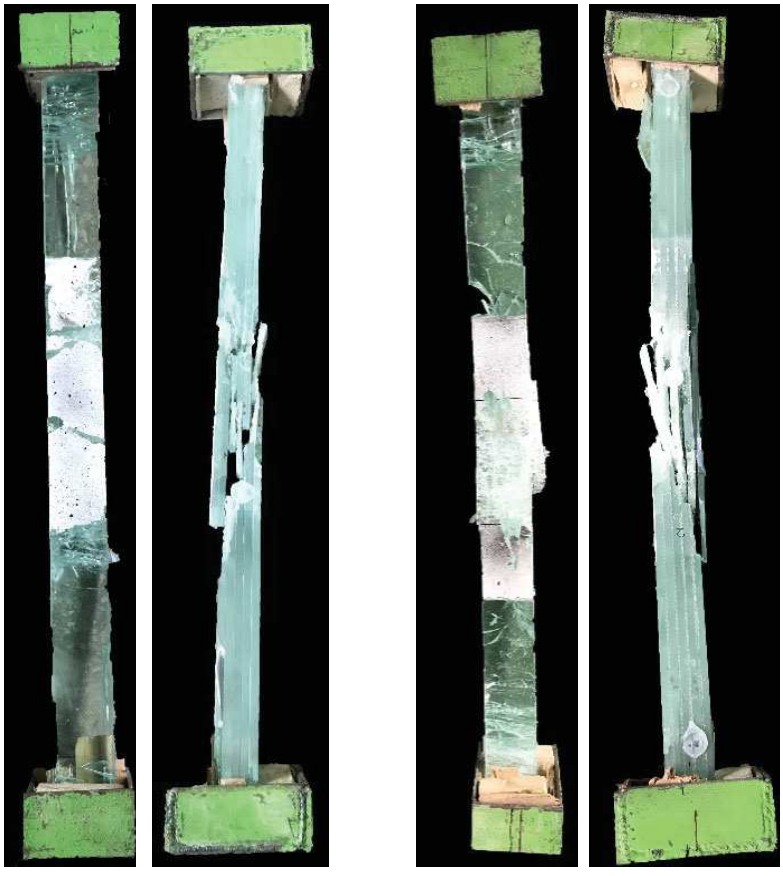


Fig. 7. The prototype samples after the destruction and assembling them in the project position; a) column of the brand KS - 2.1; b) column of the brand KS - 2.2

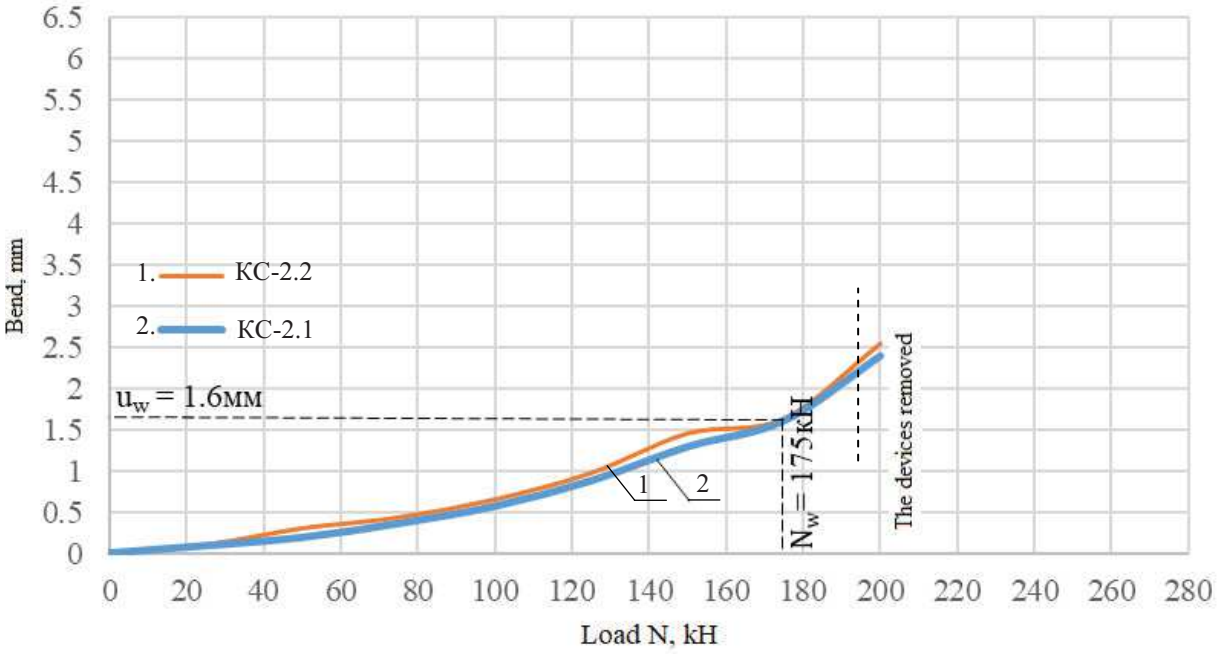


Fig. 8. The graphs of the dependence of the bend of the columns on the load in the plane "XZ"

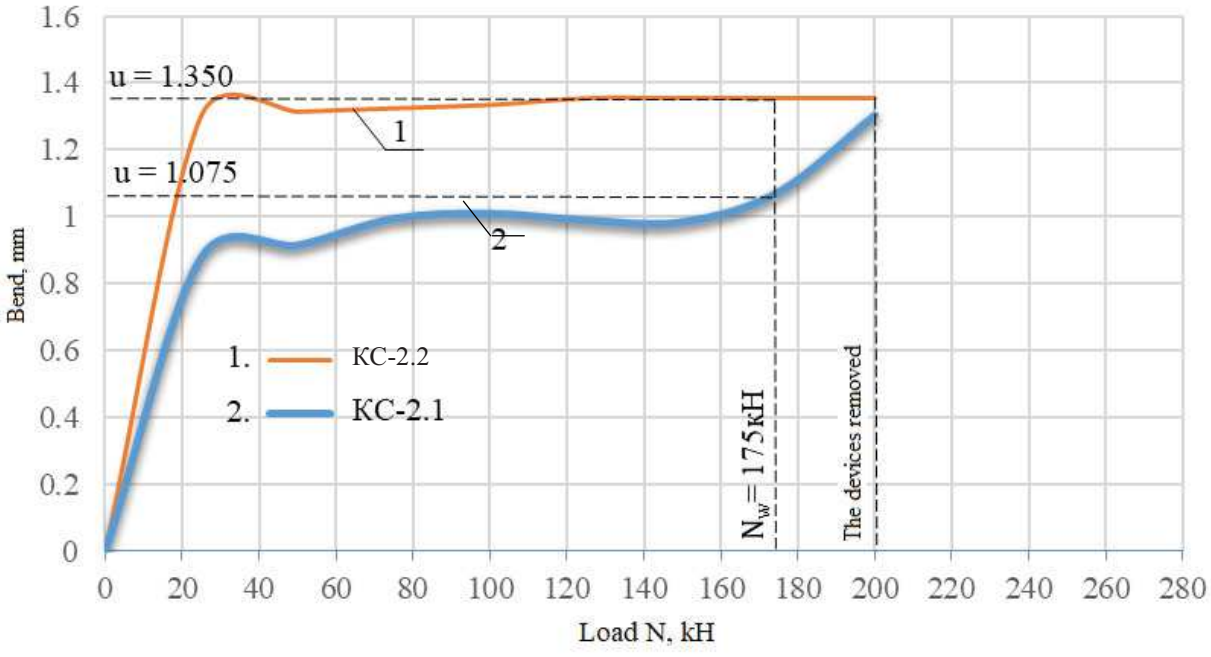


Fig. 9. The graphs of the dependence of the bend of the columns on the load in the plane "XY"

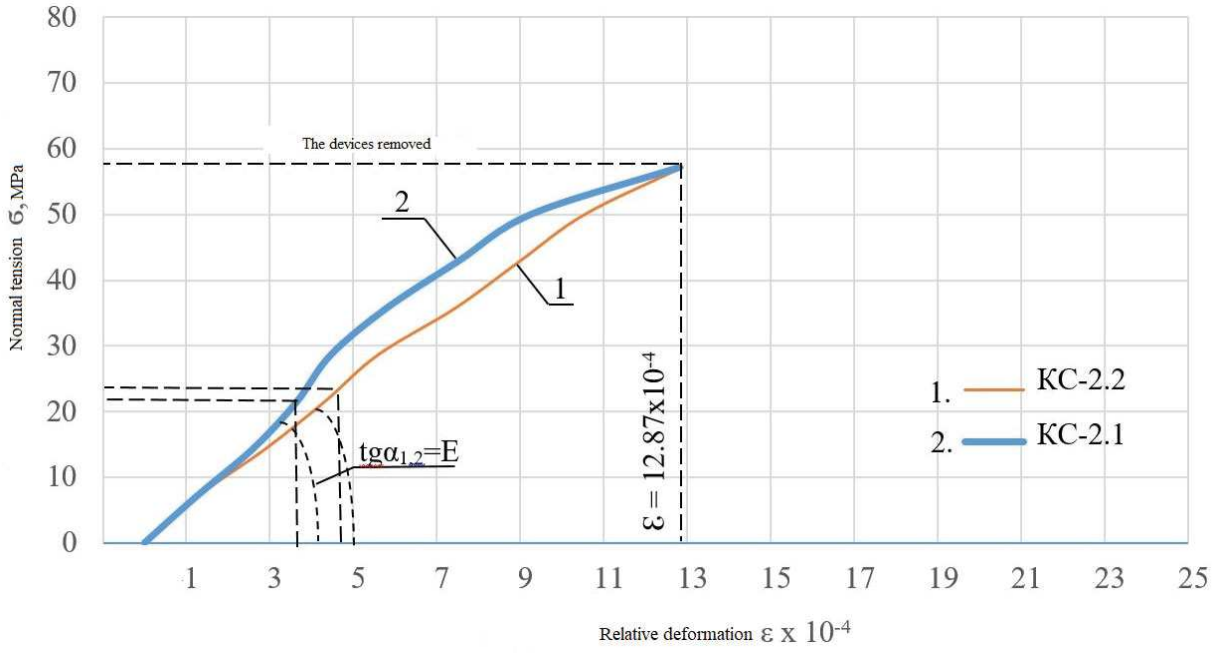


Fig. 10. Graphs of dependence of relative deformations on external glass surfaces from normal tension

After having analysed the graphs of the dependence of relative deformations on normal tension, according to Hooke's law, the modulus of elasticity of the triplex glass E (Tab. 3) was obtained.

Table 3.
General results of experimental research

Series	Brand of column	Maximum tension σ, MPa	Modulus of elasticity of triplex glass tgα = E, GPa
I	KS-2.1	77.14	49.81
II	KS-2.2	75.71	51.10

The difference between the modulus of elasticity of the triplex glass of the prototype samples was 2.52%, which does not exceed the permissible 15%.

4. Conclusions

1. The possibility of using the method of digital image correlation for the study of deformations of glass multilayer columns has been experimentally tested.
2. The column of the brand KS-2.1 with one layer of film between the glass layers collapsed at Nsr = 270 kN, and the column of the brand KS-2.2 with a double film layer was destroyed by Nsr = 265 kN. It may indicate that the number of film layers in a multilayer glass column with vertical layers of glass does not sufficiently affect the bearing capacity of the column, but the deformability of the glass column of the brand KS-2.1 with one film layer was higher than with two KS-2.2.
3. The analysis of relative deformations allowed to determine the reduced elastic modulus of triplex glass, which for both grades of the experimental prototype samples was in average of E = 50.5 GPa.

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