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METHODOLOGY AND RESULTS OF THE SERIES P-2 GLASS SLABS DURABILITY TEST

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Abstract. The paper presents the results of studies of glass plates of series P-2 for durability, which were made of float glass sheets, the methodology of experimental studies of glass plates for durability, as well as the design of the test facility. The analysis of literature sources on the subject made it possible to study the main factors of application of glass slabs as load-bearing structures. Glass is characterized by high strength, but glass structures are not widely used because of the possibility of their sudden brittle fracture and the lack of reliable calculation methods. The strength and reliability of glass structures depend on the type and strength of glass, manufacturing technology, the magnitude of external load and the duration of its action.

Glass structures are characterized by the phenomenon of rheology and sudden brittle fracture, so the study of their durability, at different levels of external static load will ensure their reliable operation for the required time. Durability of a structure is the time from the beginning of static load action, which does not exceed the destructive load, with its further endurance until the destruction of the structure. For experimental studies of the durability of glass slabs, there was a need to create a research technique to ensure the stability of the external static load during the entire experiment with the possibility to record the growth of the deflection of the glass slab, the time and the nature of the failure up to the very moment of their sudden brittle failure.

The paper describes the methodology and presents the initial results of the experimental study of glass beam slabs for durability. The slabs were hinged to two supports and operated as a single-span beam under a steady static load. Based on the experimental data obtained on the fracture of glass slabs during the action of a steady static load, we can try to predict their durability.

Keywords: glass strength, glass slab, fracture time, durability of glass slabs, glass defects.

Introduction. The modern trend in urban architecture creates the need to use energy-efficient and environmentally friendly materials while creating non-standard architectural forms. Such materials include glass. Its main advantages are transparency, high strength, environmental friendliness. In recent years glass structures are increasingly used as supporting structures for slabs and coatings, columns, frameless facades, in the construction of pedestrian bridges, etc. The use of such transparent structures allows maximum use of sunlight thus constructing more energy-efficient buildings.

Statement of the problem. When designing glass structures, there are factors that require detailed research, namely: brittle fracture of glass, defects on its surface and their impact on strength characteristics of the material, its durability in reliable operation. Defects on the glass surface (scratches, microcracks, and chips) affect the strength and durability of glass structures, leading to surface stress concentrators. The effects of these defects depend on the quality and type of glass, the operating conditions of the structure, and the magnitude of the applied load. Thus, the durability and strength of glass is a topical and little-studied problem, which requires study using new methods of experimental research of glass structures.

Analysis of recent research. The results of research glass slabs performance are presented by a number of scientific works. Experimental studies of the strength and deformability of multi-layered glass beams and plates are presented in the works of Cherevko M. [1] and Osadchuk T. [2-3], and studies of glass columns are presented in the works of Tkach R. [4-5]. All these works were carried out under the supervision of Professor Demchyna B.G. at National University «Lviv Polytechnic».

The effect of surface defects of glass (cracks, scratches) causing surface stresses can be modelled with the help of linear-elastic mechanics of fracture of solid body [6]. But despite the fact that the arising stresses in the glass under load may be lower than the destructive ones, the cracks located on the surface may increase. This phenomenon is called pre-critical crack growth. In [7] the phenomenon of subcritical crack growth is described, modelled on the basis of the Paris P. force law and Walker K. This law has been taken as the basis for the CARE/LIFE software, which predicts the reliability and durability of structures. The main provisions of the Evans E. and Wiederhom S. force law describing crack growth in glass as a function of stress intensity coefficient are presented in works [8-11]. Dependences for static, dynamic and cyclic fatigue are presented in works Nemeth N. [7] and Viens M. [12].

Purpose and objectives. To develop the design of the test rig and the methodology of the glass slab durability test and to study glass slabs for durability, with single-span hinged-supported slabs operating under constant static load, and to record the growth of their deflections, time and character of destruction until the very moment of their destruction.

Research methodology. Considering the above tasks, it was decided to develop an installation for testing glass plates for durability in such a way that it is possible to test glass plates for different values of stable static load, for a long time, while measuring the deformation of the plate throughout the duration of the test. A schematic of the test setup is shown in Fig. 1.

The method of testing the glass slab for durability consisted of the following. The experimental sample of glass slab 2 was placed on the metallic support Table 1, made of a metallic angle bar (L50×5). The plate was supported by articulated-moving and articulated-non-moving supports 4. External vertical constant static load P on the glass slab was created by suspended weights 6, through a metal frame with a roller 7. Frame 7 was suspended from the glass slab in the middle of the span, the roll to measure the deflections of the slab. The weights 6 were made of metal round bars, which were carefully weighed before the test.

Under the action of a constant static load, the glass slab deflected during the time of application of this load, after which the deflections stabilized, and just before collapse sharply increased. To measure the vertical displacements (deflections) of the plate, a clock-type micro indicator 5 with a division value of 0.01 mm, fixed to the frame 3, was installed. The deflections in the middle of the plate through the hole in the roll were measured with the help of micro indicator. In turn, frame 3 was made of a metal angle bar (L20×3) and rested on the glass plate through hinged supports 4, which eliminated the need to measure the deformations of supports. Thus, the deflections of the glass slab from the beginning of its loading to the moment of slab failure were measured using the micro indicator. The YI Dome Camera 360 – 8 was used for continuous recording of the micro indicator displays, as well as the moment of plate collapse, which performed real-time video recording during the entire time of the experiment.

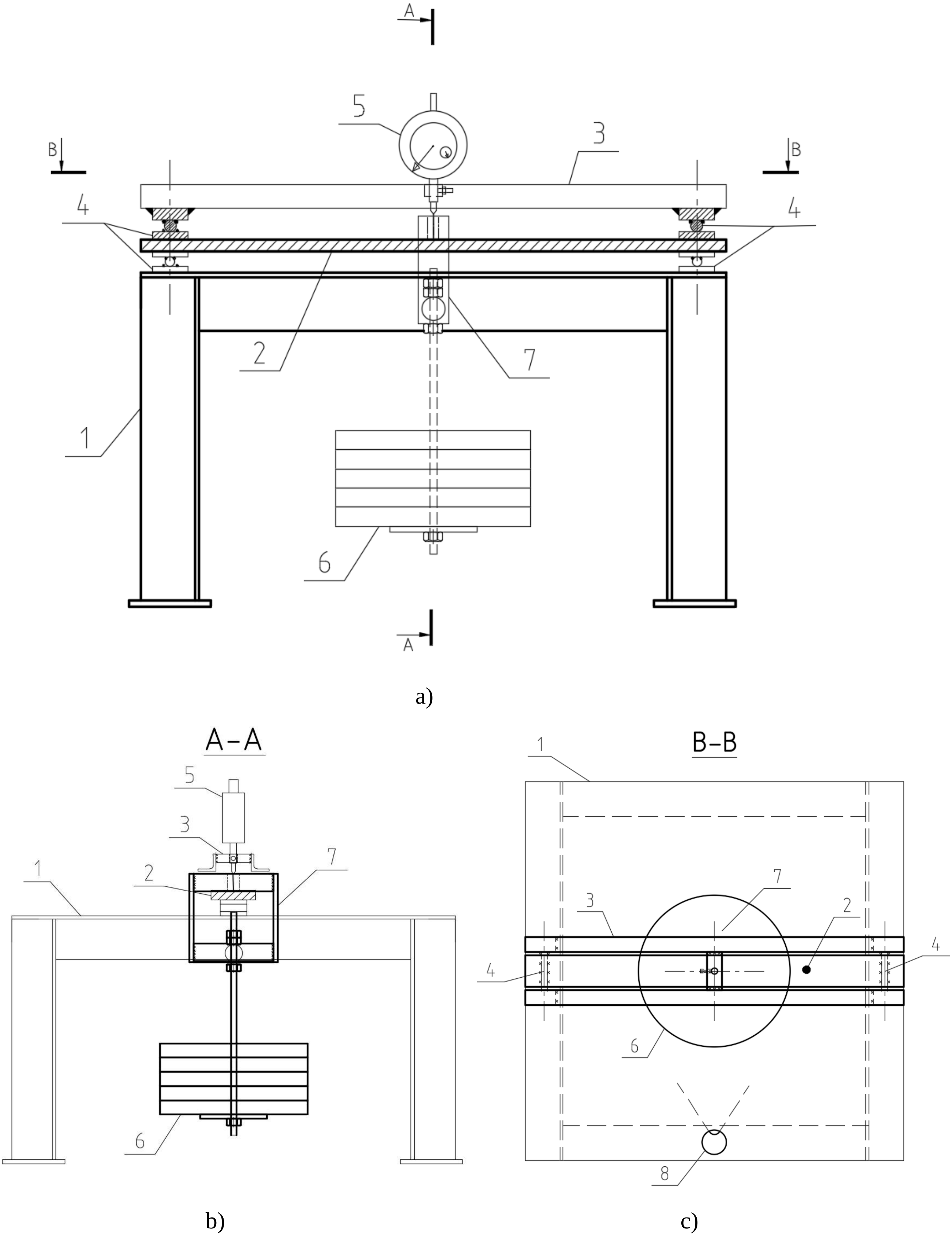


Fig. 1. Schematic diagram of the installation for testing the durability of glass plates:
a – front view of the installation; b – view A-A; c – view B-B;
1 – supporting metal table; 2 – glass test plate; 3 – metal frame for mounting of measuring instrument; 4 – hinged supports; 5 – micro indicator of clock type; 6 – load; 7 – frame for mounting of load; 8 – video camera

According to this methodology, the glass slab worked as an articulated single-span beam loaded with a static load. The value of the constant static load on the plate was taken as a part of the breaking load F, namely 0.6F, 0.7F, and 0.75F, obtained experimentally for similar samples with the same loading scheme. The general view of the installation for testing glass plates for durability is shown in Fig. 2, the image from the video camera during the test and after fracture of the test specimen is shown in Fig. 3.

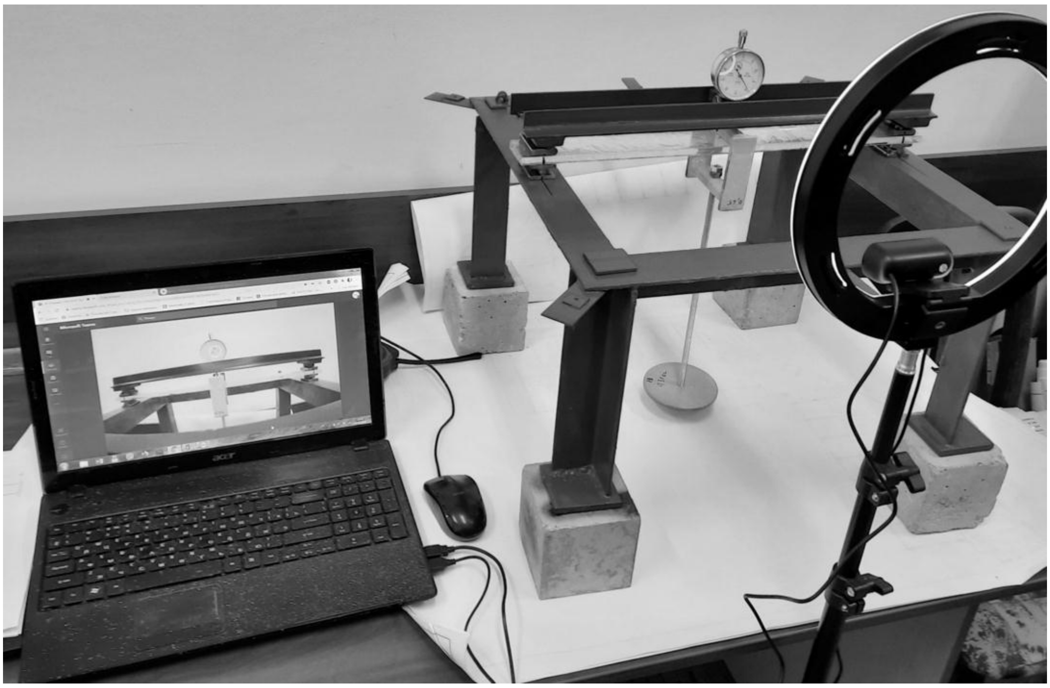
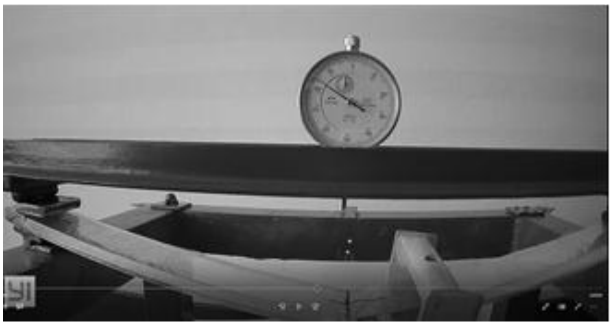


Fig. 2. General view of the installation for testing the durability of glass plates

a)



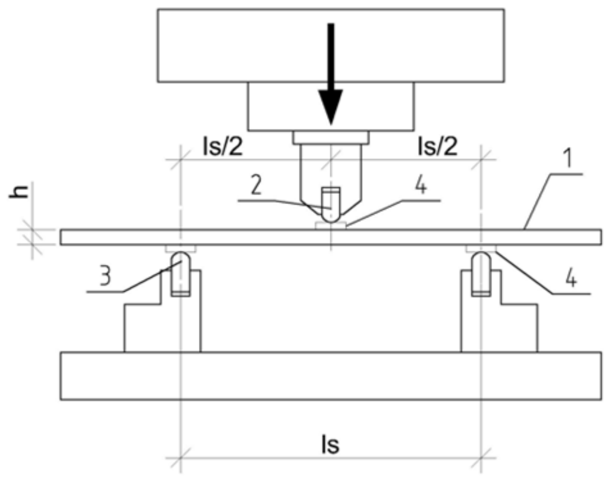
b)

Fig. 3. Image from the YI Dome Camera 360°:
a – in the process of testing; b – after fracture of the prototype

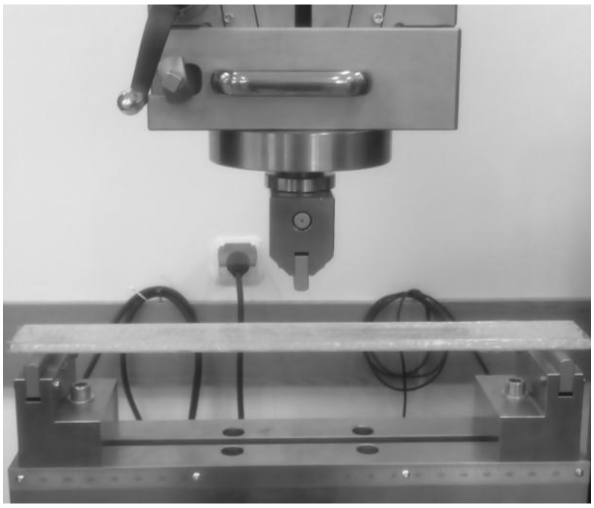
Research results. To conduct experiments on the durability of glass plates was made a series of plates with the size in plan 500×50 mm, a thickness of 10 mm. The material of the experimental samples – sheet float glass M4, according to DSTU B V.2.7-122:2009 [13] and DSTU N B V.2.6-83:2009 [14] with the following physical and mechanical properties: compressive strength of 700 MPa, tensile strength – 30 MPa, the bending strength – 15 MPa (the characteristic ultimate bending strength, which affects the quality of the end and type of glass – $f_{g.k}$ = 45 MPa), density – 2500 kg/m^3.

To determine the experimental breaking load during the bending operation of the test specimens, four test plates PS-2.1...PS-2.4 was pre-selected and tested for three-point bending according to ASTM C158-02(2017) [15]. The specimens were tested for bending under uniformly increasing concentrated load until the moment of fracture at a rate not exceeding the standard values for normal glass: 1.1±0.2 MPa/s according to paragraph 13.2 of ASTM C158-02(2017) [15]. The view and scheme of the experimental installation for testing glass bar slabs are shown in Fig. 4. Lab.Test 6.100.1.20 press with Test & Motion test system was used to test the prototypes. The accuracy class was according to EN ISO 7500-1. The data acquisition rate was up to 10 kHz.

The interactive control console software monitored and displayed all test data and parameters in the graphical and numerical format in real time (load, displacement, or deformation).



a)



b)

Fig. 4. Test rig:
a – principle diagram of the installation; b – general view of the installation;
1 – test specimen; 2 – bending roller; 3 – support rollers; 4 – rubber pads;
ls – distance between support rollers

The results and parameters of glass plates bending tests were obtained in the software report and are shown in Table 1.

Table 1 – Results of bend tests of glass beam plates

Title of the plate	Sizes (L×B×H), mm	Maximum load F_{max}, kN	Flexural strength σ_{bB}, MPa	Maximum deflection u, mm
PS-2.1	500×50×10	0.399	54.89	2.65
PS-2.2		0.381	51.78	2.48
PS-2.3		0.395	53.66	2.62
PS-2.4		0.521	68.77	3.32

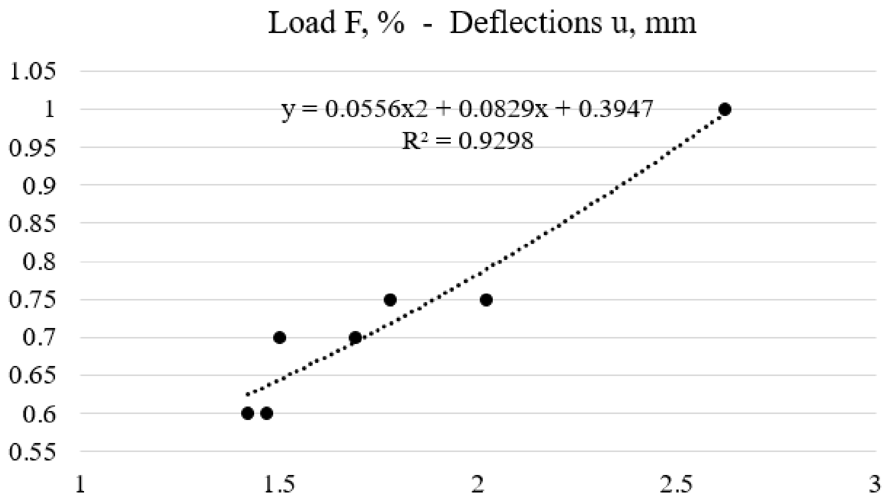
According to the results of three-point bending tests, the average value of specimens' bending strength σ_{bB} = 53.44 MPa and average destructive load F_{max} = 0.39 kN were established. These values were taken as the basis for subsequent durability tests of glass beam plates.

The destruction of test specimens during durability tests according to the presented test procedure was characterized by the formation of cracks in the middle of the span, which developed from the bottom face of the plate. In the process of research, records were kept of micro indicator readings by the time of plate failure. The destruction of all the test specimens was caused by subcritical crack growth along the bottom face of the glass. The values of destructive loads and the largest deflections for the studied series of slabs for durability are presented in Table 2.

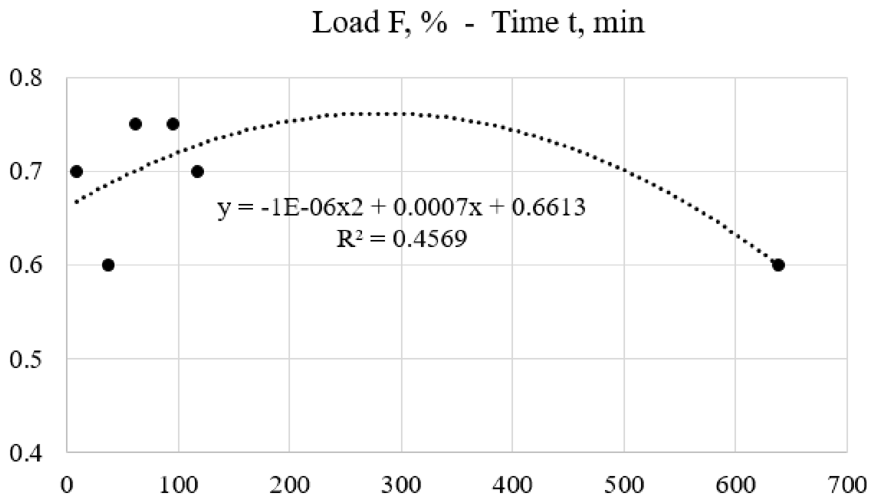
Table 2 – Characteristics of the tested boards for durability

Title of the plate	Sizes (L×B×H), mm	Load, kN	Percentage of breaking load, %	Maximum deflection u, mm
PS-2.5	500×50×10	0.294	0.75F	2.02
PS-2.6		0.294	0.75F	1.78
PS-2.7		0.274	0.7F	1.69
PS-2.8		0.274	0.7F	1.50
PS-2.9		0.234	0.6F	1.42
PS-2.10		0.234	0.6F	1.47

On the basis of the obtained data, we plotted the deflections U versus load F, time t versus load F, which are shown in Fig. 5, a and 5, b.



a)



b)

Fig. 5. Dependence plots for glass test samples of PS-2.5... PS-2.10:
a – deflections from loading; b – the time from loading

As can be seen from Fig. 5, a, and 5, b with decreasing load the deflections of the plate decrease, and the time of tests increases.

Mathematical dependencies are shown in Fig. 5, a, and 5, b obtained by approximation of experimental results of the study by the method of least squares. The load-time dependence has a rather low convergence parameter R^2 = 0.4569 which indicates insufficient convergence of the obtained results and requires additional research.

A view of the sample of the plates after failure is shown in Fig. 6. A view of the characteristic site of the plate fracture is shown in Fig. 7.

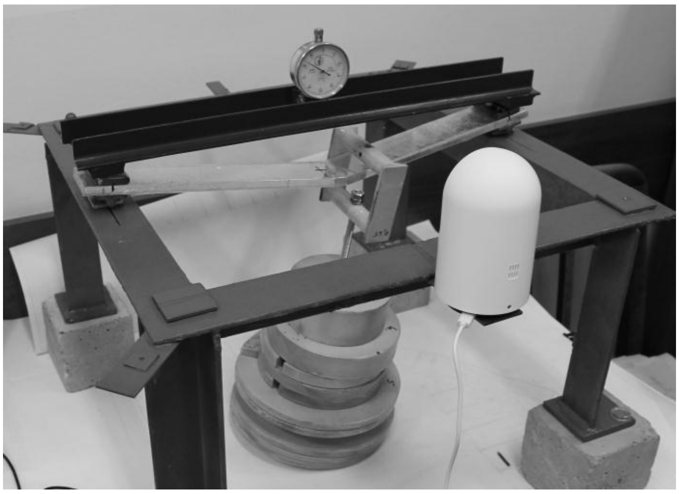


Fig. 6. View of a test specimen after fracture

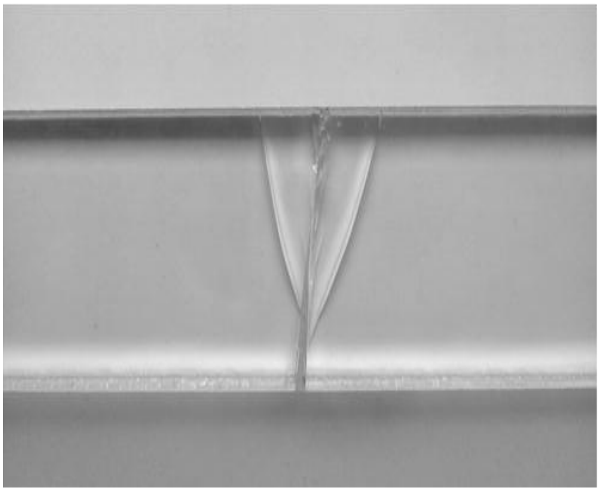


Fig. 7. The view of the characteristic place of the cut of the investigated sample of PS-2 slab

Conclusions. The following conclusions can be made based on the results of the research performed:

1. Installation for testing glass slabs for durability has been developed, which allowed testing glass slabs under different levels of static load for a long time.
2. Methodology of experimental research of glass slabs on durability, working under constant static load.
3. In the process of testing glass slabs their deflections have been measured during the whole experiment up to slab destruction, as well as the time of slabs, work under constant static load. Preliminary analysis of the results indicates the need for additional research in order to carry out their statistical analysis and obtain guaranteed durability parameters.
4. Additional analysis of the obtained data from the video camera on the character of glass slab fracture will help to investigate the growth of cracks in the glass and to establish the ratio of parameters to the stress intensity coefficient and to investigate the phenomenon of pre-critical crack growth.

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МЕТОДИКА ТА РЕЗУЛЬТАТИ ДОСЛІДЖЕННЯ СКЛЯНИХ ПЛИТ СЕРІЇ П-2 НА ДОВГОВІЧНІСТЬ

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Анотація. В статті наведено результати досліджень скляних плит серії П-2 на довговічність які були виготовлені з листового флоат-скла, методику експериментальних досліджень скляних плит на довговічність, а також конструкцію випробувальної установки. Проведений аналіз літературних джерел за даною тематикою, дозволив вивчити основні фактори застосування скляних плит в якості несучих конструкцій. Скло характеризується високою міцністю, проте широкого застосування скляні конструкції не отримали через можливість їх раптового крихкого руйнування та відсутність надійних методик розрахунків. Міцність та надійність скляних конструкцій залежить від виду та міцності скла, технології їх виготовлення, величини зовнішнього навантаження та тривалості його дії.

Для скляних конструкцій характерне явище реології та раптового крихкого руйнування, тому дослідження їх довговічності, при різному рівні зовнішнього статичного навантаження, дозволить гарантувати їх надійну експлуатацію протягом необхідного часу. Довговічність конструкції – це час від початку дії статичного навантаження, яке не перевищує руйнуюче навантаження, з подальшою його витримкою до руйнування конструкції. Для експериментальних досліджень довговічності скляних плит, виникла необхідність створити методику досліджень яка б забезпечила стабільність зовнішнього статичного навантаження протягом усього терміну експерименту з можливістю зафіксувати зростання прогинів скляної плити, час і характер руйнування аж до самого моменту їх раптового крихкого руйнування.

В статті описано методику та представлено початкові результати експериментального дослідження скляних балочних плит на довговічність. Плити були шарнірно оберті на дві опори та працювали як однопрогонова балка під дією сталого статичного навантаження. На основі отриманих експериментальних даних з руйнування скляних плит в часі дії постійного статичного навантаження можна спробувати спрогнозувати їх довговічність.

Ключові слова: міцність скла, скляна плита, час руйнування, довговічність скляних плит, дефекти скла.

МЕТОДИКА И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЯ СТЕКЛЯННЫХ ПЛИТ СЕРИИ П-2 НА ДОЛГОВЕЧНОСТЬ

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Аннотация. В статье приведены результаты исследований стеклянных плит серии П-2 на долговечность, которые были изготовлены из листового флоат-стекла, методику экспериментальных исследований стеклянных плит на долговечность, а также конструкцию испытательной установки. Проведенный анализ литературных источников по данной тематике позволил изучить основные факторы применения стеклянных плит в качестве несущих конструкций. Стекло характеризуется высокой прочностью, однако широкое применение стеклянные конструкции не получили из-за возможности их внезапного хрупкого разрушения и отсутствия надежных методик расчетов. Прочность и надежность стеклянных конструкций зависит от вида и прочности стекла, технологии изготовления, величины внешней нагрузки и длительности его действия.

Для стеклянных конструкций характерно явление реологии и внезапного хрупкого разрушения, поэтому исследование их долговечности, при разном уровне внешней статической нагрузки позволит гарантировать их надежную эксплуатацию в течение необходимого времени. Долговечность конструкции – это время от начала действия статической нагрузки, которая не превышает разрушающую нагрузку, с последующей ее выдержкой до разрушения конструкции. Для экспериментальных исследований долговечности стеклянных плит, возникла необходимость создать методику исследований, обеспечивающую стабильность внешней статической нагрузки в течение всего срока эксперимента с возможностью зафиксировать рост прогибов стеклянной плиты, время и характер разрушения вплоть до самого момента их внезапного хрупкого разрушения.

В статье описана методика и представлены начальные результаты экспериментального исследования стеклянных балочных плит на долговечность. Плиты были шарнирно оперты на две опоры и работали как однопролетная балка под действием устойчивой статической нагрузки. На основе полученных экспериментальных данных по разрушению стеклянных плит во время действия постоянной статической нагрузки можно попытаться спрогнозировать их долговечность.

Ключевые слова: прочность стекла, стеклянная плита, время разрушения, долговечность стеклянных плит, дефекты стекла.

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