Using COSMOSWORKS abilities in construction glass strength research

V Alpatov and O Y Veremeenko
Samara State Technical University, Academy of Architecture and Civil Engineering, Molodogvardeyskaya St., 194, Samara, 443001, Russia
E-mail address: avu75@mail.ru

Abstract. Considered the issues of definition maximum acceptable load on supporting construction, made of glass. Object of research is a complex construction – insulated glass unit. Glass unit has two loaded layers of three in triplex and central layer – air chamber. Air chamber is formed by rubber layer, connecting external layers of triplex by perimeter. Glass unit loading is single-sided, only on top layer. Glass unit fastening was made only in four corner points. Researches were made in program complex COSMOSWORKS. Maximum acceptable load is searched by iterative calculation with step-by-step increase of calculation load on model. Established, that covering deformation and the stress distribution in them changes linearly. The value of maximum acceptable load for glass unit with special geometrical and physical characteristics was calculated. In this article the optical, thermal and other glass unit properties were not considered. The article presents the results of glass unit analysis when only mechanical action is applied to them. Temperature effect on glass units was not considered in this article.

1. Introduction
Glass is a very interesting material. For a long time this material was used only in manufacturing of enclosing structures. It was not presented with increased requirements for strength. As a result, methods for assessing the strength of glass structures nearly did not exist [1]. But recently situation has changed. Interest in transparent constructions, that are used with significant force effects has increased [2]. One of the factors increasing this interest is the massive construction of high-rise buildings in dense urban development. Requirements for the strength of glass structures when exposed to heavy loads led to the need to assess their reliability. As a result, the need to develop methods for calculation of glass structures appeared. The concept of “glass supporting structures” appeared [3]. Glass structures began to be used not only as enclosing structures, but also as load-bearing elements in the frames of buildings and structures. Glass started to be considered as structural material, which means a material for the manufacture of a structure, parts, elements that receive load.

We should notice, that today there are no methods of glass constructions calculation, that are set out as generally accepted design standards [1]. In each situation justification of their using possibility is required. Today, the evidence justification is numerical modeling in calculation complexes, followed by necessary testing of experimental constructions in laboratories.

Numerical researches of constructions can be made in modern calculation complexes, such as Ansys, ABAQUS, Nastran, Autodesk Simulation, COSMOS, RFEM, APM, SCAD, Lira and others [4-6].
Authors made a numerical research of glass unit with dimensions 1.16×1.99 m (figure 1). Glass unit consists of three layers: triplex $t=16$ mm, air chamber $t=18$ mm, triplex $t=16$ mm. The air chamber is formed by a rubber layer, that connects layers of triplex around the perimeter. Triplex – Is A Multilayer Tempered Glass, Connected With Polymer Membrane. In This Glass Unit a Three-Layer triplex of tempered glass 8 mm + PVB + tempered glass 8 mm is used. Glass unit connection to the building frame is supposed at four points. For fastening the glass unit, it provides steel fastening elements for the system Spider $d=60$ mm. Impact of snow and wind on glass unit during exploitation is supposed.

The described glass unit is the object of research. The target of the research is to determine the maximum permissible load on a glass unit.

![Figure 1. Researched glass unit.](image)

2. Materials and methods

The task of determining the maximum permissible load was formulated as a numerical research. Method of research is iterative calculations of virtual model with step-by-step load increase. The COSMOSWORKS calculation complex was chosen as the research tool. The algorithm for solving the task is to perform the following sequence of actions:
1. Creating calculation model;
2. Adding load to calculation model;
3. Structural analysis of calculation model;
4. Assessment of load acceptability.

Calculation model was created in SolidWorks program complex (figure 2). Load is added to the upper surface of the model. Calculations are performed only for a uniformly distributed load. The load is applied in steps, that is, it increases in each next calculation.

As a result of calculation model structural analysis its deformations and load in its elements are calculated. For further analysis amounts of calculation model maximum vertical displacement and maximum equivalent stresses in model elements are recorded.

The criterion for the admissibility of the applied load is taken to simultaneously ensure the strength and rigidity requirements of the glass unit. Ensuring the strength of a glass unit is assessed by comparing the calculated equivalent stresses in the elements of a glass unit with the reference value of strength limit of the material. Ensuring the rigidity of the glass unit is evaluated by comparing the calculated maximum vertical displacement with the allowable value. Acceptable amount of glass unit vertical displacement was set by $B/300=3.87$ mm according to the requirements of norms [7]. The amounts of materials strength limits are taken according to reference books [8, 9].

![Figure 2. Calculation model](image-url)
3. Results and discussions

Load increase step during calculation the stresses, was taken equal to 2 kPa. The step of increasing the load during calculating deformations was 1 kPa. Smaller step during вычислении calculating deformations was chosen because maximum deformations are achieved much faster than limit of strength (figures 2, 3).

![Figure 3. Calculated strength.](image)

As a result of performing a series of calculations with a step-by-step change in the load, stresses and displacements were obtained in the calculation model. Stresses in the rubber layer and in steel elements were not analyzed. Loads in triplex were defined by Maxwell–Huber–Hencky–von Mises...
theory. The calculation results are shown in tables 1, 2. On figures 3, 4 graphs of stress and displacement versus load are shown. The graphs are constructed by linear approximation of the calculated in program complex COSMOSWORKS amounts of stresses and displacements. The calculation results were processed by program complex MathCAD. On figures 5-7 most illustrative graphical results of model calculation with load equal 11 kPa are shown.

| Table 1. – Stress calculation results. | Table 2. Displacement calculation results. |
|--------------------------------------|------------------------------------------|
| Load, (kPa) | Calculated strength (MPa) | Tensile strength, (MPa) | Load, (kPa) | Displacement, (mm) | Limit displacement (mm) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 1               | 11.6            |                 | 1               | 1.362           |                 |
| 3               | 34.2            |                 | 2               | 2.702           |                 |
| 5               | 55.9            |                 | 3               | 4.107           | 3.87            |
| 7               | 79.6            |                 | 4               | 5.430           |                 |
| 9               | 102.3           |                 | 5               | 6.798           |                 |
| 11              | 125.0           | 120             | 11              | 14.912          |                 |

Figure 5. Stress distribution in the calculation model.

Figure 6. Calculation model deformation. View on upper triplex.
4. Conclusions
Numerical experiment established:
1. Stresses in external layers of glass unit (triplex) change linearly until reaching the glass strength limit.
2. Glass unit external layers deformations change linearly until reaching the glass strength limit. Deformation character of upper (loaded) and lower (not loaded) layers are different. Upper layer deformates as a plate, supported by four points (figure 6). Lower layer deformates as a plate, supported by two sides (figure 7).
3. Maximum equivalent stresses in glass are seen in zone of spider connection, here we should expect initial cracking.
4. We consider maximum acceptable load as load, that causes appearance of loads in glass, that are equal to strength limit. These are the peak stresses seen in areas of glass connection to a metal element spider (figure 5). Amount of accessible load is 10.9 kPa.

References
[1] Zubkov V and Kondratieva N 2013 *Flexural strength of sheet glass* (Samara: SamLuxPrint)
[2] Zubkov V and Kondratieva N 2018 *MATEC Web Conf.* **196** p 02015
[3] Zubkov V and Kondratieva N 2008 Characteristics of calculation of flat glass in translucent structures. Glass performance days. New Delhi pp 27-29
[4] Alpatov V 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **463** pp 032103
[5] Alpatov V et al 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **456** 012010
[6] Balzannikov M et al 2016 *MATEC Web Conf.* **73** p 01012
[7] Standard SP 20.13330.2016 Loads and impacts, http://docs.cntd.ru/document/456044318/
[8] Standard GOST 111-2014 Colorless sheet glass, http://docs.cntd.ru/document/1200119804
[9] Handbook TROSIFOL 2005 (Troisdorf: Kuraray Specialities Europe GmbH) 53840