Saimaa University of Applied Sciences
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LOAD-BEARING GLASS STRUCTURES

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ABSTRACT
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Saimaa University of Applied Sciences, Lappeenranta
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The purpose of this thesis was prove the possibility of using glass in buildings as a load-bearing element. For centuries, its use is limited to functions such as window glazing. In recent decades, the improvement of science and industry has allowed the use glass as a structural element. However, the design of such structures is still problematic.

The study was conducted at the architectural studio "Studio 44" as an example of glass covering of courtyards in the reconstruction of the General Staff Building of East Annex, located between the Palace Square and River Moika. Structures of glass coating is a system of interconnected diagonal steel trusses and glass beams, which consist of a multilayer laminated glass.

For the calculation of the glass beam a design-computer complex StructureCAD v.11.1 was used, realizing the finite element method in the form of the method of displacement. To confirm the calculations conducting tests was necessary. The testing of the glass beam of the General Staff will be made at CRIBS Kucherenko (Central Research Institute of Building Structures) in Moscow. The test models will be scheduled on uniform and no-uniform loads.

The results of the calculations and the tests proved the possibility of using glass as a load-bearing element, but because of the high cost of the material, the use is not widespread. This is compounded by the lack of normative documents for the calculations bearing glass. For each design a special certificate and confirmed tests are required.

Keywords: load-bearing glass structure, glass covering, glass beam, structural glass elements

CONTENTS

1 INTRODUCTION

The glass roof is a good looking, non-crushing ceiling with light pouring from the sky. It provides a sense of infinite space, a sense of an open space and at the same time a reliable roof over your head. In addition, this structure allows the efficient use of daylight, and thus meets the requirements of energy conservation.

The basis for the construction of such roofs is a framework. Glass size for the cell must provide maximum light transmission for security applications. Glass should not collapse under its own weight in horizontal or slope position. Its strength should be enough to withstand wind and snow loads, and also produced (with the use of appliances) repairs and maintenance works on the roof.

The first example of the usage of glass as a material for bearing structures was a glass exhibition pavilion, constructed by Glasbau Hahn, Frankfurt am Main in 1951. The glass walls of the pavilion are crowned by a glass roof, which lies on the glass as I-beam cross section. (Wikipedia, 2009)
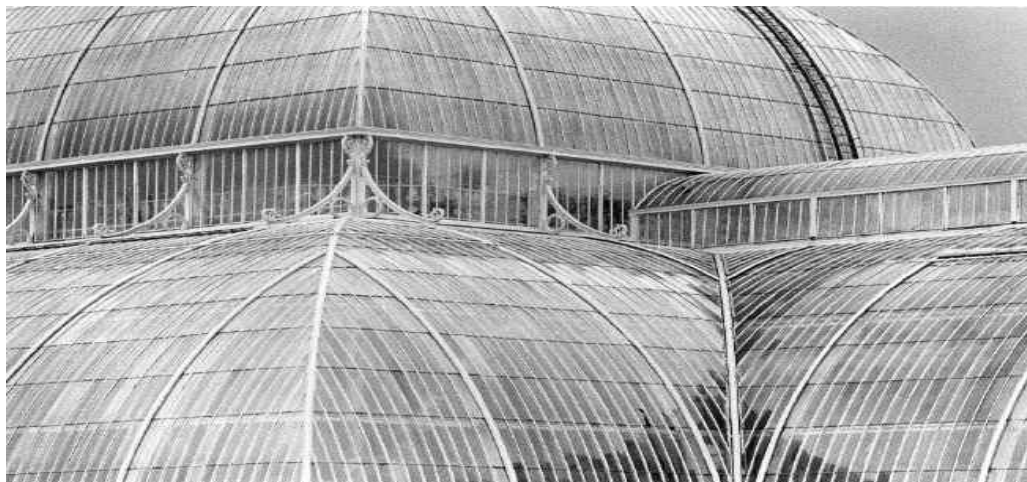
Figure 1.1 Glass pavilion with steel frames in Frankfurt

But if the said pavilion served as a demonstration of the capabilities the firm, the glass pavilion built in Badenweiler, had served the purposes of utilitarian, connecting the two buildings. The glass panel roof of the pavilion is based on 4 glass beams with the span of 6.2 m and with the step of 1.7 m. The beams are glued together from three sheets of annealed glass, the inner sheet being 15 mm thick, the outer being

10 mm. The outer sheet has some great height, and formed the bottom of the beam gutter attached steel cable for a partial relieve of stress in the beam, as well as insurance in case of failure. (Wikipedia, 2010)

In contrast to the described construction glass roof over the dining room of the Technical University (Dresden, Germany), built in 2006, does not contain steel cables or braces for the insurance. Main beams with the span of 5.8 m connected to the secondary specially designed cross-shaped connecting nodes of high-alloy steel. (Technical University, 2006)
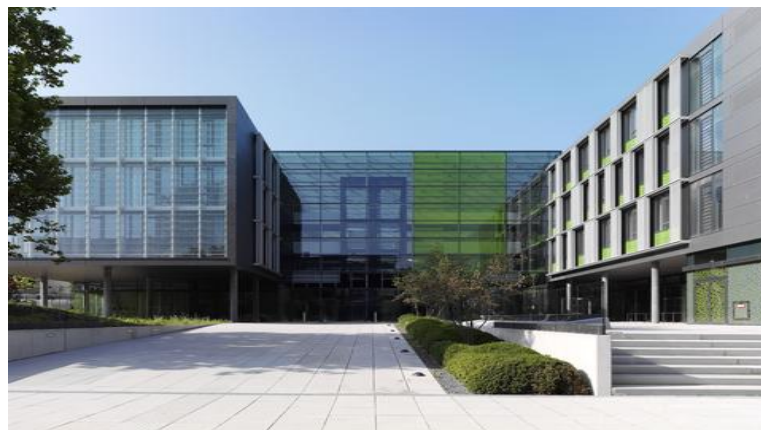

Figure 1.2 Technical University in Dresden

Beams themselves are glued together from four layers of annealed glass of aged 12 mm thick, with strength analysis included only in the two inner layers, outer layers are there to protect the internal mechanical damage. For admission to the application of design and tested three modules in 1:1 scale were built. The final test was to test the residual load capacity in the damaged outer layers of the main beam. The design has stood the test, and the deflection was 24 mm. (Makonstroy, 2009)

Another full glass building was built in 2008. It's an Art Museum in Stuttgart. In 1999, the design of the Berlin architectural office Hascher + Jehle emerged as the winner of an international competition. The Stuttgart natives wanted "to create a calm, elegant building corpus that is clearly anchored in our time." In March 2002 the construction began building. Hascher and Jehle's final design was a distinctive yet unobtrusive architectural gem which blends in well with Stuttgart's overall inner-city architecture. (Kunstmuseum, 2010)

Figure 1.3 Kunstmuseum in Stuttgart

Visible from a distance, the glass cube encloses a stone cube that contains around one-fifth of the exhibition floor space. The far greater part of the 5,000 square meters, however, is located below the Kleinen Schossplatz (Small Castle Square). (Kunstmuseum, 2010)
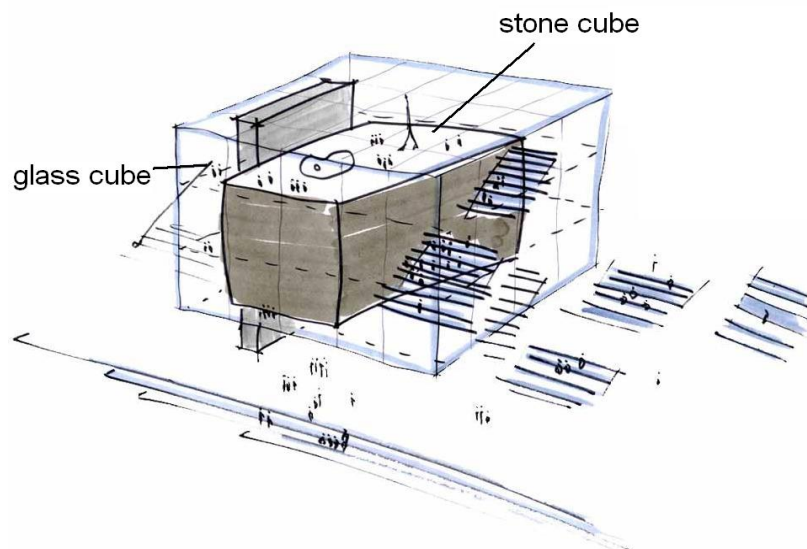
Figure 1.4 Preliminary sketch of museum

The new building that is home to Stuttgart's Art Museum consists of an above-ground glass cube and extensive exhibition areas housed in the fully renovated underground tunnels originally built in the sixties. The sides of the glass cube are 28.8 m in length and 26 m in height. Its roof can be partially opened and is supported by a grillage of girders. The glass walls are suspended from the roof girders. The load-bearing structure of the cube facade consists of glass fins. This design solution means the

building envelope achieves an extremely high degree of dematerialization and offers an undisturbed view of the heart of the town from inside the building. (Werner S.)

Figure 1.5 Fragment of glass roof

On the basis of world experience in designing structural glass, the architectural workshop "Studio 44" under the leadership of Nikita Yavein was offered the version of covering the translucent structures of yards of The East Wing of The General Staff Building, reconstructed at the museum and exhibition complex of the Hermitage. The ideology of the reconstruction is to restore enfilade constructs (suite of rooms), baroque perspective, hanging gardens and large exhibition halls, illuminated by skylight. The basic principle of constructing display rooms of the General Staff Building was decided to make a suite of rooms. First, this principle derives from the historical of the architect Carlo Rossi plans: a building consisting of separate enfilades. Secondly, it should be universal for the exhibition halls of the Hermitage complex: the Old, the New Hermitage and the Winter Palace.
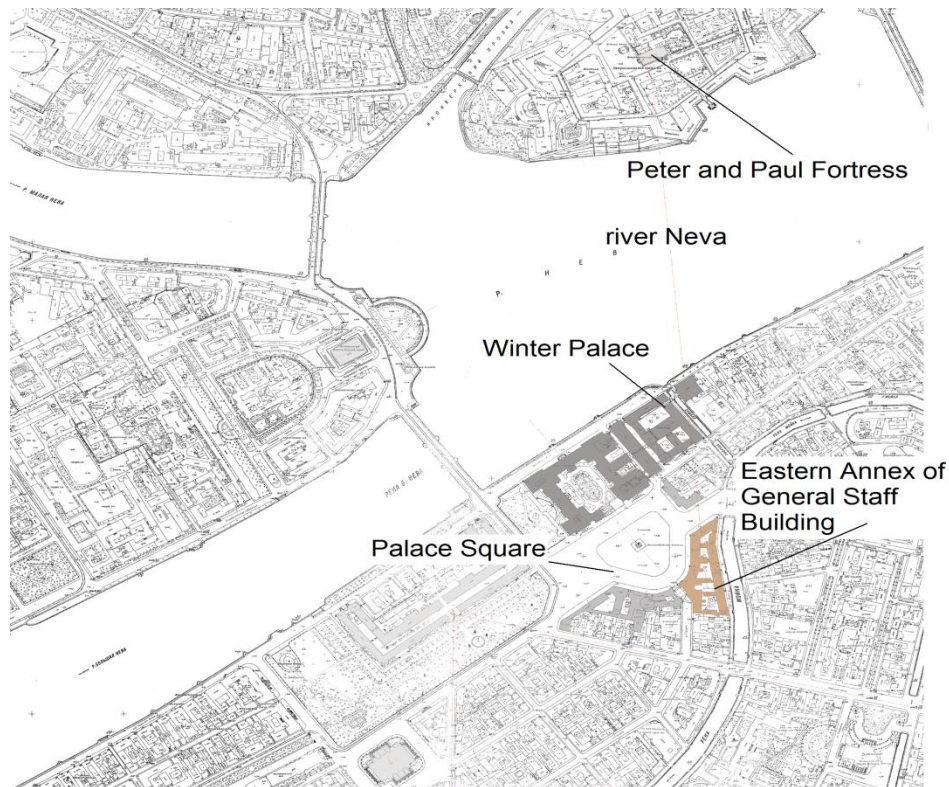
Figure 1.6 Location of the East Annex of the General Staff Building

Most of the permanent exposition will be located in the enfilades (suite of rooms), encircling the perimeter of the complex. Large-scale temporary exhibitions will be held in the courtyard spaces. To do this, five courtyards are overlapped with glass roofs and converted into large new enfilades. It is an alternation of large exhibition halls, embedded in cross-body on the second floor and with hanging gardens on the platforms. This enfilade is not straight, but tapering, converging in perspective, that multiplies its retracts the funnel effect, originally founded in the planning of the building whose courtyard spaces are subject to the principle of perspective convergence. (Explanatory note of the project, 2008)

2. GLASS COVERING OF COURTYARDS OF GENERAL STAFF BUILDING

The General Staff Building was designed by a Russian architect of an Italian origin named Carlo Rossi and built in 1820-1830. The main façades are facing The Palace Square and the Moika river embankment in the immediate vicinity of Nevskiy prospect (avenue) in the historical centre of St. Petersburg (Appendix 2). There are five floors and five spacious courtyards in the building. (Explanatory note of project, 2008)
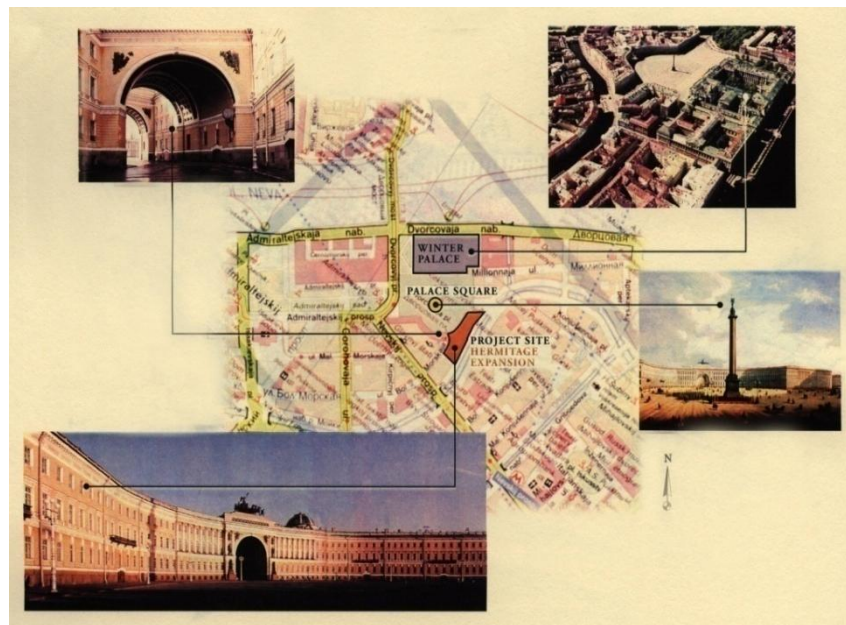
Figure 2.1 City the plan of General Staff Building

Originally, the Eastern Annex, which has been assigned to the State Hermitage Museum by now, accommodated Ministry of Finance, Ministry of Foreign Affairs and some other ministries of the Russian Empire. Since 1917 the building has been occupied by various institutions and organisations. (Wikipedia, 2010)

The General Staff Building is a landmark of federal significance registered under №108 and is located within the boundaries of the protection area for historical and cultural landmarks (TSN 30-306-2002 Saint-Petersburg). (Explanatory note of the project, 2008)

Figure 2.2 The facades of General Staff Building

The facades of the General Staff and its historic interiors are subject to thorough restoration and changes are unacceptable. However, the composition and the character of the premises differ sharply from that required of a modern museum. In terms of functional and spatial organization of the East Wing of the General Staff it's comparable to the zone of mixed uses of the quarter of courtyards with household courtyards, combining a single façade outside. It is necessary to highlight the many complex constructions inside the building that are integrating it into a coherent whole with the spaces of the palace and the museum complex of the Hermitage and the images of the St. Petersburg area. (Explanatory note of the project, 2008)

In the course of field and archival research a comparative analysis of the General Staff and other parts of the Hermitage complex, measuring, observing and sketching, architects (Appendix 1 "List of main architects and designers") came to the conclusion that in the construction of buildings a number of principles, analogies and associations, whose development will be reconstructed without violating the idea of Rossi and turned in use in the General Staff Building in the organic continuation of the Hermitage spaces need to be taken into use. These principles are as follows:

  – The idea of baroque perspective;

  – The principle of enfilade (suite of rooms);

  – The structure of Hermitage hanging gardens;

  – «New Large Gaps» - Hermitage exhibition halls in the transverse yard building. (Explanatory note of the project 2008)
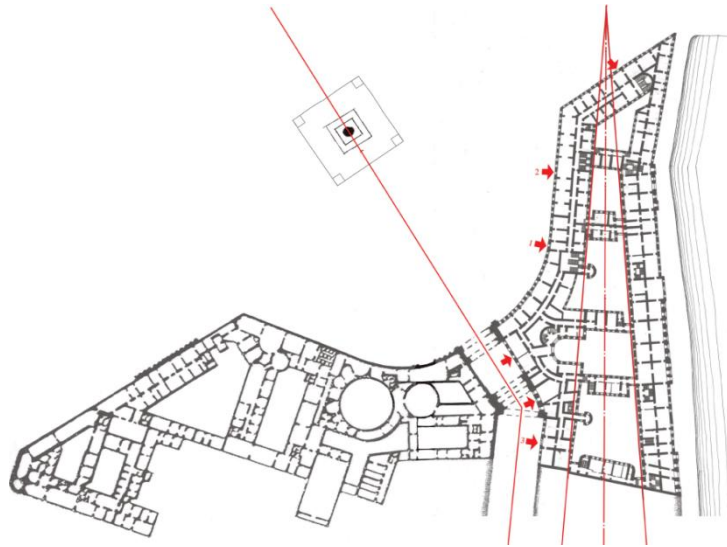
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Figure 2.3 The idea of baroque perspective

Each of these principles are mentioned in a separate section of the project concept, but they are all united in the idea of the New Grand Enfilade and specified in the proposals for the organization of functional flows and museum trails vary in the hierarchy of display spaces complemented by the architectural decisions of the top natural light. And each of the sections of the project concept aims to preserve the monument and to find a new, but not exogenous growth from within. (Explanatory note of the project, 2008)

The architectural reconstruction project of East Annex of General Staff Building provides a covering of existing internal yards by translucent structures. Structures of such coverings represent the system of spatial diagonal steel trusses, which are basing on internal building walls. As internal yards have the complex geometrical forms on the plan, and also their sizes are different, the supporting trusses have various distances and they have different height in different yards.
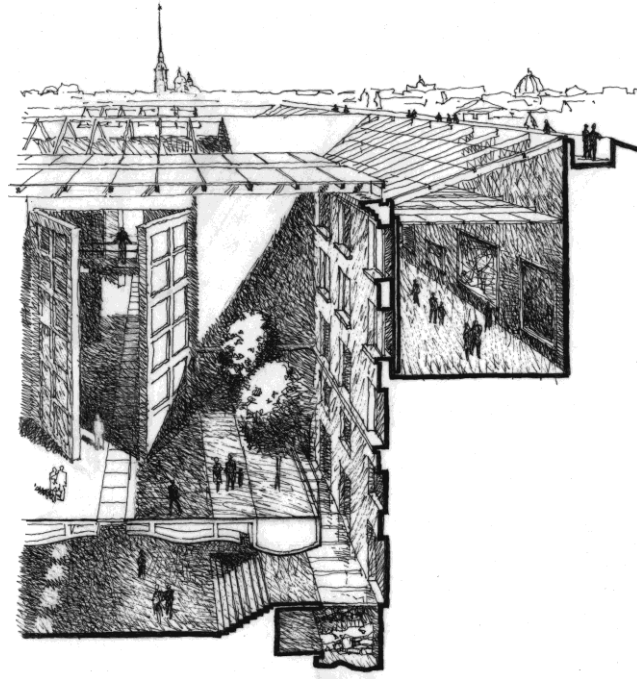
Figure 2.4 The cross-section of courtyard

The step of supporting trusses is 6.2 meters. On the purlin, with the help of spiders, a double glazed window is stacked with a slope to the trusses, which create the top translucent covering. For the leaning of the overlap, on the internal walls steel trusses and binding beams are put, which allocate the load on the brick piers. All metal structures are protected by fire-protection compounds for the accomplishment the necessary fire resistance level (60 min). (Explanatory note of the project, 2008)
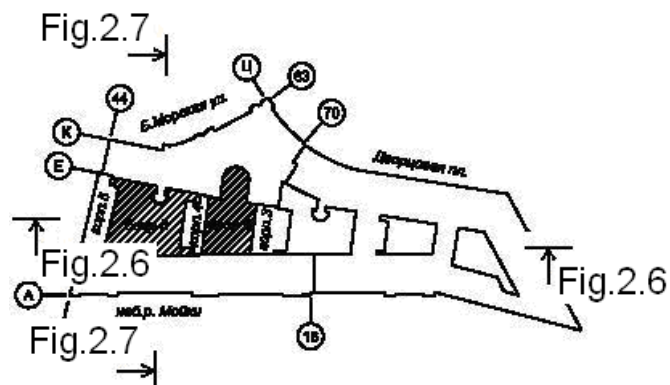
Figure 2.5 The building site of Eastern Annex of General Staff Building

Designs coatings households represent a system of nine (for the 5th of court), and four (for the 4th of the yard) steel trusses, located between the buildings and

enclosures resting on reinforced belt, made along the edges of the internal walls of courtyards, metal spacing of beams, the decoupling form with each other .
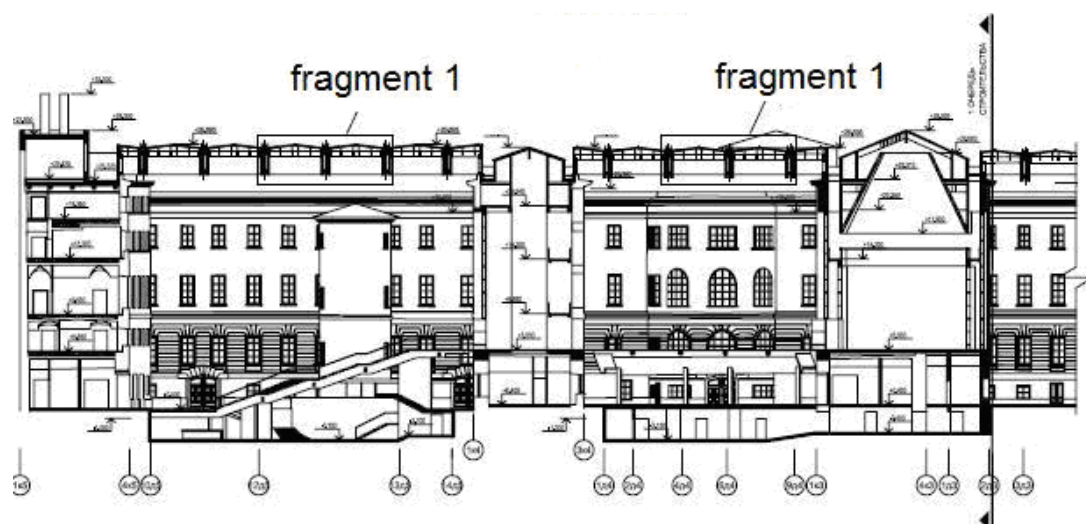
Figure 2.6 Longitudinal section of courtyards №5 and 4

The maximum span of the trusses is no more than 39 m, the step installation trusses being 6.2 m. To the top chord at the intersections of bracing with a step 1.7 m, fixed bearing glass beams, which are the basis for supporting the glass elements of the roof. (Explanatory note of the project, 2008)
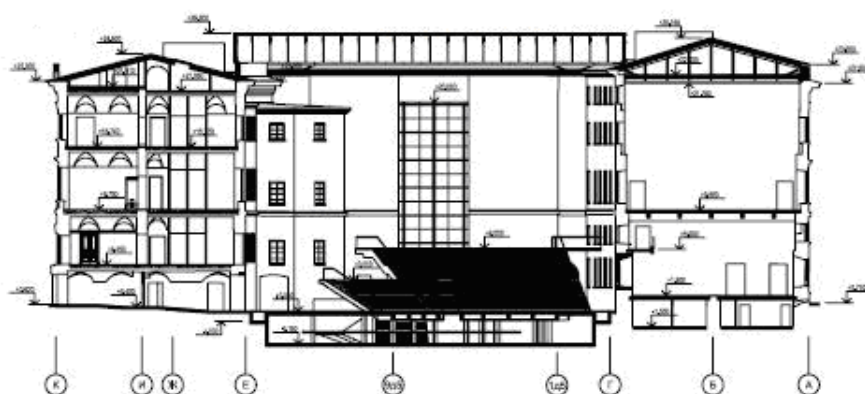
Figure 2.7 The cross-section of courtyard №5

In one of the supporting units support conditions on the reinforced concrete structures a truss belt using fluoroplastic gaskets is arranged to slide the bearing.

fragment 1

section 1-1
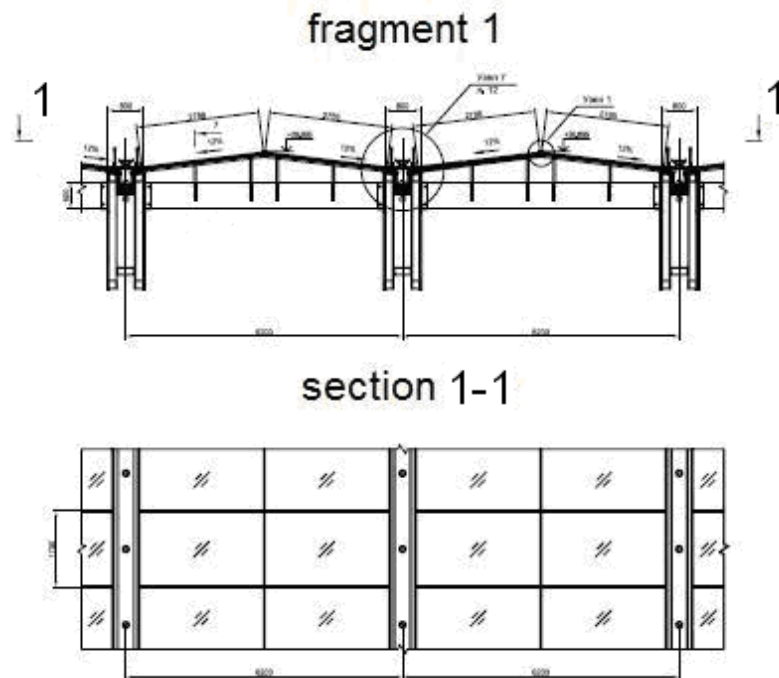
Figure 2.8 The fragment of glass covering

Drainage trays, devices of heating and block systems for the hoisting of exhibits are located in the coupled trusses. The beams are hanged to the lower belts of trusses, catwalks for the washing of translucent structures moving along the beams. Fire safety is provided by fire sprinkler system (the entire length of the glass beams on both sides are dispensers). Smoke is removed through transom in the last beams. (Explanatory note of the project, 2008)

3 VARIANTS OF STRUCTURES

The usage of glass as a building material has a long tradition because of transparency. Its primary usage for windows led to the fact that existing standards and regulations are primarily determined by the requirements of relevance in this area. Unfortunately, the standards also have a lot of noticeable flaws. All this leads to the unsatisfactory situation, which has various negative consequences. In Russia the situation is complicated by the lack of any documentation for load-bearing glass. Doubts about the correctness of design and the lack of generally accepted methods of calculation are often time consuming and expensive due to laboratory tests. On the other hand, large load-bearing glass structures are unsatisfactory from an economic and architectural point of view and small sized are unacceptable from a security perspective.

As a result, the basic requirements for the design of glass load-bearing structures are:

1. Durability, which requires:
   − Comprehensive and clear decision for the to structure.
   − Accuracy, flexibility and scope to match the current structures.
   − Options of structures must comply with only one physical aspect and not be dependent on test conditions. When hazardous scenarios in case of damage to the surface, the main danger to the load-bearing element should be based not on the load, but should be on the defective of the surface.
2. For a better understanding of the design tests must be conducted (in order to obtain meaningful and sustainable results.)
3. The main risk in respect of load-bearing glass structures will be discussed and resolved.
4. Safety (calculation of structures in light snow and wind loads);
5. Thermal insulation (calculation of structures subject to specified heat transfer coefficient of resistance);
6. Smoke system (number and type of smoke elements);
7. Internal drainage of condensate;
8. Removal of moisture from the outer surface of structure;

9. Sealing and insulation places adjacency to the elements of structural;

10. Acoustic permeability;

11. Design heating in the winter time.

3.1 Standards and regulations for load-bearing glass structures

Written standards need to be taken into consideration together with research, design and construction experience when a new construction project is started. However, they tend to lag behind the advanced research and new construction projects. With this in mind, it is not surprising that there are shortcomings in the standards and guidelines for the design of glass in construction. Construction under the direction of these regulations is increasing, but still not yet at a level with other construction materials. Design guidelines and standards such as the IStructE on constructive glass (IStructE: Structural use of glass in buildings) and a project document for engineers IABSE's on the glass (Structural use of glass, Structural Engineering document no. 10) is very small and rare and they require regular updating to keep pace with the rapid development of science. Designing legal instruments is still in its infancy, architects and designers have more freedom to develop glass structures and this inevitably leads to the fact that there is a lot of variety in the differences of the calculation of load-bearing glass structures. (IStructE, 1999; IABSE, 2008)

Standards vary in detail and complexity, ranging from the development of charts in some countries to more detailed guide calculations in other countries. None of the existing standards do not provide the basic parameters for calculating the load-bearing glass, which are necessary for the development of new designs. In addition, there is a lack of comprehensive standards for the manufacture of glass, and its characteristics, such as laminating and thermal hardening, which lead to significant changes in the field of quality control.

There is a perception that it is necessary to develop a single international standard for the load-bearing glass. However, this standard will only provide consistent basic properties and methods in the calculation of glass structures, not excluding the alternative, supported by tests. For nearly 10 years an instrument for glass design

was being developed, but this standard has faced some difficulties. Recently, the European Commission has developed a Eurocode for load-bearing glass. The commission has yet to approve this proposal, it's currently discussing the project and a negative response will, of course, be a big blow to the construction community working with glass.

The American National Standard 'Standard Practice for Determining Load Resistance of Glass in Buildings' ASTM E 1300-04 provides extensive charts to determine the required thickness of glass plates. It is based on the glass failure prediction model by Beason & Morgan and on the finite difference stress and deflection" analysis by Vallabhan (Vallabhan, 1983). Resistance is defined using a target failure probability of 8‰. ASTM E 1300 applies to vertical and sloped glazing in buildings exposed to a uniform lateral load and made of monolithic, laminated, or insulating glass elements of rectangular shape with continuous lateral support along one, two, three or four edges. The specified design loads may consist of wind load, snow load and self-weight with a total combined magnitude less than or equal to 10 kPa. The standard does not apply to other applications such as balustrades, glass floor panels and structural glass members or to any form of wired, patterned, etched, sandblasted, drilled, notched or grooved glass or to any glass with surface and edge treatments that alter the glass strength:

$$q \leq LR = NFL \cdot GTF$$

The verification format is with q being the uniform lateral load, LR the 'load resistance', NFL the 'non-factored load' (based on a 3 s load duration) and GTF the so-called 'glass type factor' (load-duration dependent, see below). (ASTM E 1300-04, 2004)

The important difference with respect to European design methods is that this verification format is based on loads and not on stresses. Furthermore, it does not use any partial factors. The NFL is determined from charts given for various geometries, support conditions, glass thicknesses and for monolithic as well as laminated glass. The GTF combines glass type and load duration effects and is given for single panes (Table 3.1) as well as for insulating glass units.

Glass type	Short duration load	Long duration load
ANG	1.0	0.5
HSG	2.0	1.3
FTG	4.0	3.0

Table 3.1 Glass type factors (GTF) for a single pane of monolithic or laminated glass.

The Canadian National Standard 'Structural Design of Glass for Buildings' CAN/CGSB 12.20-M89 deals with soda lime silica glass panes exposed to uniform lateral load. Like the American National Standard, it is based on the and a target failure probability of Pf = 0.008 for the resistance. It is important to notice that in contrast to ASTM E 1300-04, which uses a 3s reference duration for the resistance, CAN/CGSB 12.20-M89 is based on a 60s reference duration. This is due to the fact that the Canadian Standard, published in 1989, is based on ASTM E 1300-94 while the 3s reference duration was only introduced in ASTM E 1300-03. (CAN/CGSB 12.20-M89, 1989)

In the thesis, because of the lack of standards and GOSTes for the calculation of bearing glass structures, SNIP 2.01.07-85 "Loads and pressures", SNIP 23.01.1999 "Building Climatology", building codes SN 481-75 "Instructions for the design installation and operation of double-glazed windows" and Technical Regulations "About the safety of glass and its products used in buildings" are used. In Russia, this regulation is the only guide for the calculation of similar structures. The project of technical regulations developed by the initiative group of the Expert Council for legislative support of the development of glass industry in the Committee of State Duma in Economic Policy of Russian Federation, entrepreneurship and tourism with the participation of Russian enterprises for the production of glass products. This document authorizes the use of European standards and regulations, except for requirements that can not be used due to climatic and other peculiarities of the Russian Federation. For each design requires a special certificate and verified tests are requared.

3.2 Innovations in design and production of glass constructions

Glass objects are not limited by environmental requirements but preserve transparency and lightness in a glass structure. At the moment with the latest developments engineers can:

- Determine the mechanical properties of glass, in particular, the ability to predict the strength and the variability of glass.

- Improve the quality of laminated glass, which maked it less stratifiable, longer to use and being improved appearance.

- Develop a high-performance mechanical connection to reduce stress concentration while enhancing the productivity of glass.

- Develop a rigid adhesives and gaskets, such as in glass Sentry Glass Plus with pad DuPont, which enables the use of laminated glass as plywood. (DuPont SentryGlass)

- To design large autoclave plants that will allow producing laminated glass large 3.5 m to 15 m and more than 8 m to 20 m.

- Develop a glass-metal connection, which eliminates the need for drilling holes in the glass and reduces the stress concentration around the joints.

These innovations allow the use of glass as a load-bearing element, but despite these successes there are some problems and obstacles for further development:

- Reduction or elimination of metal elements from glass often requires expensive testing.

- Large glass panels are now often limited by the problems due to transport, access and replacement.

- In most design guidelines no difference is made between key load-bearing glass elements and secondary structures of glass.

- The large size and the importance of glass elements mean that the quality of manufacturing and tolerances are in the foreground. Despite improvements in the quality of lamination, there are several manufacturers and installers who can install and laminat glass with a low tolerance of high quality production work.

- Connection type (stress concentration in the holes) still determines the type of construction, for example, glass thickness, number of layers, type layers, etc.

3.3 Load-bearing glass structures

New architectural solutions offer a wide variety of applications of glass as a constructive building material, which makes it necessary to supply the calculation of the structural elements of glass and assessment of their carrying capacity on a new footing. Today, there are no methods of calculating the load-bearing glass elements described as norms and rules; in each case an application is required, supported by a series of tests. Experiments and discussions lead to the creation of the concept of reliability, based on which can be developed, methods of calculation and dimensioning, as well as standards for the design, taking the necessary safety requirements into consideration.

Glass amorphous is a substance, but also it is a durable material, due to a close arrangement of atoms. This crystal lattice occurs during solidification of the viscous substance in solid form, not allowing crystallizing in a regular lattice (Fig. 3.2).

○ oxygen (O)
● silicone (Si)
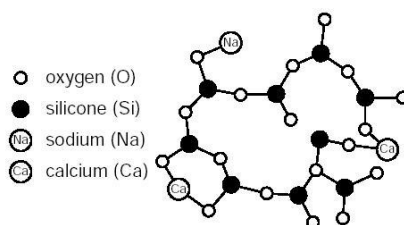Ⓝ sodium (Na)
Ⓒ calcium (Ca)

Figure 3.1 Schematic image of an irregular lattice of sodium-silica glass

The glass consists of silica fused at high temperatures mainly with borates and phosphates. Also, the glass exists in nature formed by a vulcano or meteorite formed. Despite his irregular grid, which places the material somewhere between the solid and the liquid phase, there is sufficient adhesion molecular structure for mechanical strength. (K.Leitch K., 2005.)

Table 3.2 Chemical composition of soda-silica and borosilicate glass, in compliance with the Eurocodes (EN 572-1:2004) and (EN 1748-1-1:2004).

	Soda lime silica glass	Borosilicate glass
Silica sand SiO_2	69 – 74%	70 – 87%
Lime (calcium oxide) CaO	5 – 14%	–
Soda Na_2O	10 – 16%	0 – 8%

	Soda lime silica glass	Borosilicate glass
Boron-oxide B_2O_3	–	7 – 15%
Potassium oxide K_2O	–	0 – 8%
Magnesia MgO	0 – 6%	–
Alumina Al_2O_3	0 – 3%	0 – 8%
others	0 – 5%	0 – 8%

According to ASTM E1300-04, there are common terms for different types of glass. Use of non-specialized titles makes glass easy to work with for design the engineers. Table 3.3 shows the terms used in the construction.

Table 3.3 Terminology types of glass

Level of residual surface compression	Terminology in the present document	Other frequently used terms
(almost) none	annealed glass (ANG)	float glass
medium	heat strengthened glass (HSG)	partly toughened glass
high	fully annealed glass (FTG)	annealed glass; (thermally) toughened glass
unspecified (HSG or FTG)	heat treated glass	

Table 3.4 Physical properties of soda-silica and borosilicate glass (EN 1748-1-1:2004; EN 572-1:2004).

Density	ρ	kg/m^3	2500	2 200-2 500
Knoop hardness	HK$_{0,1/20}$	GPa	6	4.5-6
Young's modulus	E	MPa	70000	60 000-70 000
Poisson's ratio	ϑ	–	0.23	0.2
Coefficient of thermal expansion	a_T	10^{-6} K^{-1}	9	Class 1: 3.1-4.0 Class 2: 4.1-5.0 Class 3: 5.1-6.0
Specific thermal capacity	c_p	J kg^{-1} K^{-1}	720	800
Thermal conductivity	λ	Wm^{-1} K^{-1}	1	1
Average refractive index within the visible spectrum	n	–	1.52[§]	01.05.10
Emissivity (corrected)	ε	–	0.837	0.837

The most important physical properties of soda-silica and borosilicate glass are listed in Table. 3.4. One of the most important properties of glass is the chemical resistance to aggressive environment, which explains its popularity in chemical industry and makes glass one of the most durable materials in construction. The optical properties depend on the thickness, chemical composition of the coating (film) of load-bearing glass. The most obvious feature is the transparency in the wavelength range from 380 nm to 750 nm. Due to the interaction with O_2 much UV is absorbed. Wavelengths > 5000 nm locked group SiO. This is the greenhouse effect - visible light penetrates through the glass and heats the space inside, and locked long waves on the surface of glass. (DuPont SentryGlass)

The degree of sound insulation fireproof glass, consisting of hardened fire-resistant glass, meets the degree of insulation of float glass the same thickness and it varies from about 28 to 35 dB (R_w), depending on the thickness of the glass. With the help of a thin layer of gel (about 1 mm), or the use of laminated glass with PVB film, R_w value can be increased to the level of 36-39 dB. (Chesnokov A., Zlotopolskiy A., 2007)

Load-bearing glass has an almost perfect isotropic behavior, brittle fracture and it is not plastic. The theoretical strength of load-bearing glass reaches almost 6,000 MPa, and sometimes even 10,000 MPa. But as in all brittle materials, tensile strength of load-bearing glass depends largely on surface defects, which are sometimes visible to the naked eye, as well as the size of the elements of the nature and intensity of the load and residual stresses. The chemical composition and physical properties of the glass allows its use in construction as load-bearing element. With the help of modern technology these characteristics may improve.

3.2.1 The production process of glass structures

Currently, the production of float glass is the most popular basic production processes, and is about 90% of all flat glass in the world. The main advantages of this manufacturing process, represented by Pilkinton brothers in 1959, is its low cost and wide availability, superior optical quality glass and large size sheets. Mass

production of glass, improved over the past 50 years, has become affordable enough to be widely used in the construction industry. Over the past two decades, advances in glass technology have facilitated the analysis of structural methods (e.g. finite element method), which allows the use of glass as a structural element. In the design of glass structures laminating sheets for stock are often used in the event of a sudden failure of one of the elements.

For the structural usage of glass hardening is the most important method of treatment. Float glass is heated to about 620°- 675°C in the furnace and quenched (rapid cooling) jets of cold air. This effect cools the surface, which freezes and then freezes, and the core glass. During the first seconds, the cooling process leads to tensile stresses on the surface and compressive inside. If the initial temperature is too low, the relaxation can not take place and tensile stresses can cause the glass to shatter in the oven. As soon as the surface temperature drops below 525°C, the glass solidifies and relaxation will be terminated immediately. The temperature distribution is approximately a parabola. Cooling leads to a characteristic residual compressive stresses on the surface and inside the glass. For best results, the stress state, this process should occur when the surface is hardened at a time when a maximum difference in temperature is set weakened at the original strain. The hardening of borosilicate glass is difficult even under high pressure air or quenching in a liquid because of its low coefficient of thermal expansion. (Haldimann M., 2006)
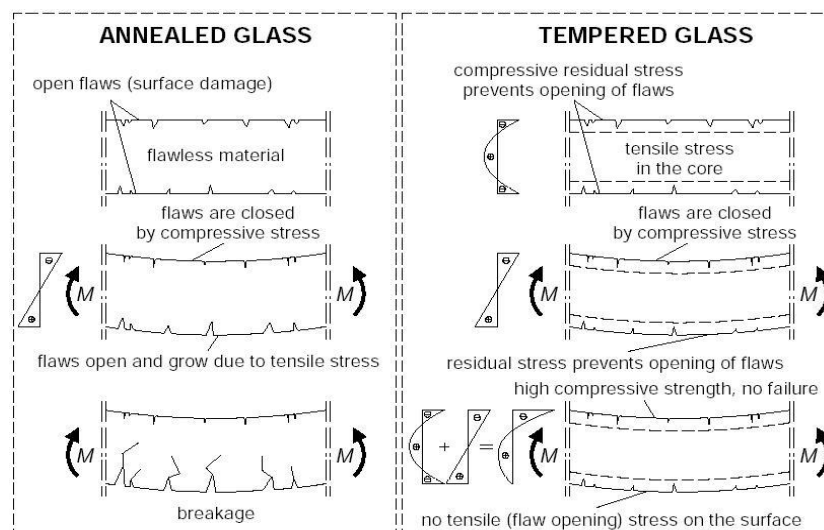

Figure 3.2 The principle of tempering glass

The idea is to create a favorable residual stress field due to tensile stresses within the glass and compressive near the surface. The core of the glass does not contain defects and, therefore, has good resistance to stretching. Inevitable defects on the surface of glass can only grow if they are subjected to tensile stress.

Breaking the scheme is a function of the energy stored in the glass, residual stresses and stresses due to loads. As an example, Figure 3.3 shows the breakdown of the structure of samples, loaded with a common axis of double rings. A fully tempered glass has the highest level of residual stresses and, as a rule, divided into small, relatively harmless fragments of about $1cm^2$, tempered glass is called "safety glass". Heat strengthened glass "is a compromise between a good structural performance and a large enough fragmentation in the split". Burned glass is a standard float glass without any admission. (Haldimann M., 2006)
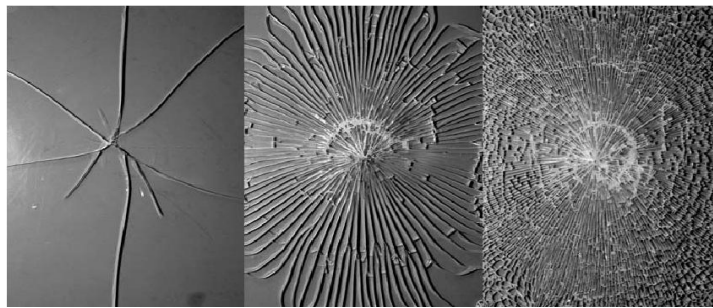

Figure 3.3 Comparison of the destroyed structure: baked glass (left), heat tempered glass (middle), fully tempered glass (right).

Typical residual surface compressive stresses ranging from 80 MPa to 150 MPa for fully calcined soda-silica glass. The most important parameter for the quenching of the glass is the coefficient of thermal expansion of glass and heat transfer coefficient between glass and air. In particular, the coefficient of heat transfer is difficult to estimate, it depends on the quenching (geometry, impact bars, air pressure, air temperature, etc.) and, therefore, varies from one manufacturer of glass to another. (Haldimann M., 2006)

Standard thickness for fired glass is 3, 4, 6, 8, 10, 12, 15, 19 and 25 mm. Typical maximum dimensions are of 3.0 m x 6.0 m sheet, and 3.2 m x 8.0 m, possibly even more on special order. Burned glass may have corrosion cracking under the

influence of long loads. This phenomenon is due to the presence of microcracks at the edges of the sheet under the action of water, which lengthens the cracks. There is a threshold voltage, after which the stress-corrosion cracking is no longer a significant factor, it is 7N/mm2. (Wilson P., Vasilchenko-Malishev G., 2006)

Another phenomenon, which affects bronzed glass, is thermal shock. Selected areas of glass can be warmed unevenly in the sun, the temperature difference between the surface and its main site at the junction with the frame may be 33° C. This leads to cracking due to internal stresses resulting from temperature differences between the two different parts of the same sheet of glass. So often, experts recommend using windows, consisting of two components, for example, triplex and toughened glass. ("Roof" Journal, 2008)

Also, laminated glass plays an important role in structural usage. It consists of two or more sheets of glass, bonded together by a transparent plastic layer. Glasses may be the same or different in thickness and may also be different in the heat treatment. Most of the lamination process is in an autoclave at a temperature of about 140°C. The thickness of the glass depends on the duration of the load and temperature.

For the roof glazing the choice depends on the transparency requirements and safety design in each case. Safety can be achieved in three ways: by using annealed glass, a triplex or glass with deposited layers. The strength of annealed glass is 4 - 5 times higher than usual because of a special heat treatment. A triplex, which is also called laminated glass, is a kind of "sandwich" consisting of two or more sheets of ordinary polished glass, by proper fastening together by a special layer. Such glass has a high impact resistance, and fastened the layer does not allow it to break into fragments during fracture. The behavior of laminated glass on impact can be seen in Fig. 3.4. ("Roof" Journal, 2008)
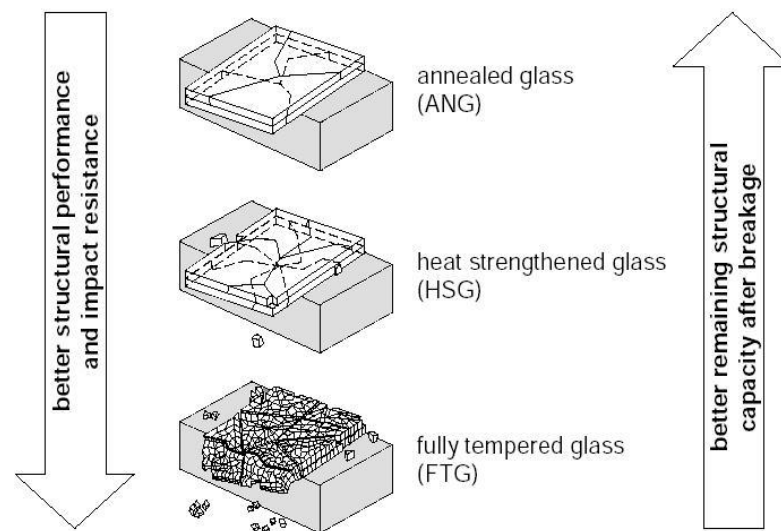
Figure 3.4 The behavior of laminated glass made from various types of glass (Sedlacek., 1999).

In the laminated glass a polyvinyl viscoelastic layer (PVB) is usually used. The physical properties of the film depend on the temperature and duration of the load. When damaged, the glass layer tries to keep the pieces in place, thereby reducing the chance of injury from falling glass. A nominal thickness of PVB film is 0.38 mm. In general two – 0.76 mm or four – 1.52 mm are used in the form of one. Heat treatment is sometimes advisable to use up to 6. Also used transparent resin with a layer thickness from 1mm to 4mm are sometimes used to achieve special properties, such as soundproofing DuPont's SentryGlass Plus. The layer is blocking ultraviolet radiation. The penetration of ultraviolet (UV) rays of the sun or fluorescent sources, causes damage to interior fabrics, furniture and works of art. (Saint Gobains Glass; DuPont SentryGlass)

Fire protection in the laminated glass is also carried out by using layers. Under the influence of fire, glass cracks but remains in place and formes an impenetrable shield of insulating foam.
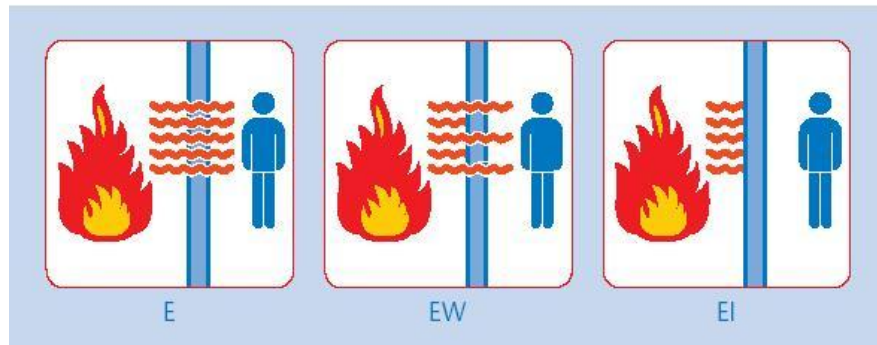
Fig. 3.5 The classification of fire resistance

To ensure fire safety in the supporting structure must consist of fireproof glass must have a the fire resistance class G30, G60, G90 and G120 with the individual requirements of protection. According to a classification in EN 13501-2 the fire resistance performance is expressed by letters, explaining the functional requirement and numbers explaining the performance time in minutes (Fig. 3.5):

E: Integrity – provides a physical barrier against flame, hot gases and smoke.

EI: Integrity & insulation – provides a physical barrier against flame, hot gases and smoke as well as a reduced surface temperature and resistance against spontaneous ignition on the unexposed side.

EW: Provides a physical barrier against flame, hot gases and smoke and offers a reduced heat radiation. (SCHOTT, 2010)

Glass is initially a brittle material, but the calcined glass (float) has a relatively low tensile strength and is broken into sharp shards that represent a danger of injury. Calcined glass can be read in conjunction with other materials for the production of "safety glass", which has the ability to reduce the risk of injury. Heat treatment for the production of tempered glass increases the tensile strength and changes the fragments into smaller ones (Fig. 3.6). Such a decision would certainly be better, but does not eliminate the problem entirely, since the weight of falling glass (albeit in the form of small rounded fragments) is quite significant and could cause injury.(Overend M., 2008)

Fig. 3.6 On the right figure - Laminated glass consisting of two sheets of tempered glass with a layer. On the right - Laminated glass consisting of two hardened sheets.

3.2.2 Ecological aspect

Public awareness of anthropogenic CO_2 emissions and the effects on climate change has increased dramatically in the last 10 years. There is also a growing recognition that buildings are responsible for a large proportion of CO_2 emissions - approximately 40% of end user CO_2 emissions, where heating, cooling, ventilating and lighting of buildings account for a third of all global CO_2 emissions. In an attempt to reduce energy demand in buildings there have been rafts of national and international targets and regulations for energy efficient buildings.

Glazing has traditionally been regarded as a weak element in the environmental performance of buildings, but the benefits of glazing such as the introduction of natural light into a building and the resulting sense of wellbeing for building occupants should not be underestimated. In addition there have been rapid technological advances in glass leading to substantial improvements in the thermal transmittance (U-value) and the solar heat gain coefficient (G-value) of glazing units. The improvements are such that the frame is often the major source of thermal bridging in a contemporary glazed façade. (Aleksandrov N., 2007)

When using special coatings, for example, SentryGlas cover LOW-E, increasing energy efficiency in buildings. It can also help design more efficient thermal insulation load-bearing glass and load-bearing glass from a more effective control of the transmission of ultraviolet radiation. There is also load-bearing glass with a low heat

when using fillers between the layers, such as gas. To provide reliable protection from sun and glare light is used to manage, with electric drive, blinds foil in the space between the panes. (Saint Gobains Glass; DuPont SentryGlass, SCHOTT)

There are evident regional differences in this area. In colder climates (e.g. Northern Europe) there are conflicting requirements of maximizing light transmittance and minimizing heat loss. The latter is often strictly regulated. The preferred solution in these climatic regions is to use large area glazing but with high performance glass sometimes in conjunction with passive energy efficient systems such as natural ventilation, double skin façades or shading devices. In warmer climates (e.g. The Middle East region) it is impossible to have a full glass façade and achieve performance without relying heavily on mechanical air conditioning systems.

3.2.3 Basic data for designing the glass cover courtyards of the General Staff Building

The East Wing of the General Staff, located at The Palace Square, 6-8, letter A (Annex 1) has the following characteristics:

- Object purpose and use: administrative non-resident building.
- Area of the plot: 15,562 sq.m.
- Climatic area – IIв (SNiP 2.01.01-82.)
- Design winter ambient temperature – - 26°C (SNiP 2.01.01-82.)
- Design snow load for region III according to SNiP 2.01.07-85* -1.8 kPa (180 kgf/m^2)
- Normative wind load for area II according to SNiP 2.01.07-85* - 0.3 kPa (30 kgf/m^2)
- Number of floors: 4-5, basement.
- Courtyard area: 3,600 sq.m.
- Land plot area: 15,562 sq.m.
- Volume: 242,445 cub.m.
- Importance class— 1 (SNiP 2.01.07-85*)
- Degree of fire resistance — 1 (SNiP 2.01.07-85*)
- Class of constructive fire danger — C0 (SNiP 2.01.07-85*)

- Climatic region — IIV (SNiP 2.01.01.-82)

- The building complex and the amount offset by households — to be heated

For the calculation of the design a computing complex StructureCAD v.11.1 was used, realizing the method of finite element method in the form of displacements. It is necessary to make the collection of loads on the 1-meter running:

1. Constant loads:

    A. Double-glazing unit $a \times b = 1,7 \times 2,8m$; $\rho_{glass} = 2500\,{}^{kg}/_{m^3}$; $\gamma_f = 1,1$

        а) tempered glass t_1=15mm

        б) ordinary glass t_2=8mm

        в) ordinary glass t_3=8mm

$g_{glass}^{Norm} = \rho_{glass} \cdot (t_1 + t_2 + t_3) \cdot a \cdot b \cdot 2 = 2500 \cdot 0,031 \cdot 1,7 \cdot 2,8 \cdot 2 = 737,8kg$

$g_{glass} = g_{glass}^{Norm} \cdot \gamma_f = 737,8 \cdot 1,1 = 811,58kg$

$q_{glass} = {}^{g_{glass}}/_{1,7 \times 5,4} = {}^{811,58}/_{(1,7 \cdot 5,4)} = 88,4\,{}^{kg}/_{m^2}$

    B. Profile Schuco: $\gamma_f = 1,05$; $\rho_{Al} = 2700\,{}^{kg}/_{m^3}$

T-profile $50 \times 50 \times 3$; $g = 1,29kg \cdot rm$

$g_{maвр} = 1,29 \cdot 2,8 = 3,6kg \cdot rm$

Rectangular hot-rolled profile $50 \times 50 \times 4$; $A = 7,1cm^2$

$g_{profile} = 1,528 \cdot 2,8 = 4,3kg \cdot rm$

$g_{overall} = (g_{maвр} + g_{profile}) \cdot 2 = (3,6 + 4,3) \cdot 2 = 15,4kg \cdot rm$

$g_{Schuco} = g_{overall} \cdot \gamma_f = 15,4 \cdot 1,05 = 16,2kg$

$q_{Schuco} = {}^{g_{Schuco}}/_{1,7 \times 5,4} = {}^{16,2}/_{(1,7 \cdot 5,4)} = 1,8\,{}^{kg}/_{m^2}$

    C. Stainless steel rack: $\gamma_f = 1,05$; $\rho_{steel} = 7900\,{}^{kg}/_{m^3}$

$50 \times 30 \times 4$; $A = 5,48cm^2$ $\begin{cases} Rack\ №1: l = 0,968m \\ Rack\ №2: l = 0,815m \end{cases}$

$g_{rack\ 1} = 0,968 \cdot 7900 \cdot 0,0548 = 4,19kg$

$g_{rack\ 2} = 0,815 \cdot 7900 \cdot 0,0548 = 3,53kg$

$g_{rack}^{Norm} = (g_{rack\ 1} + g_{rack\ 2}) \cdot 2 = (4,19 + 3,53) \cdot 2 = 15,43kg$

$$g_{rack} = g_{rack}^{Norm} \cdot \gamma_f = 15,43 \cdot 1,05 = 16,2kg$$

$$q_{rack} = \left. g_{rack} \middle/ 1,7 \times 5,4 \right. = \left. 16,2 \middle/ (1,7 \cdot 5,4) \right. = 1,8 \, ^{kg}/_{m^2}$$

        D. Glass beam: $l = 5380m$; $\gamma_f = 1,1$; $\rho_c = 2500 \, ^{kg}/_{m^3}$

$$t = 12 \cdot 4 = 48mm = 0,048m$$

$$h = 600mm = 0,6m$$

$$g_{beam}^{Norm} = l \cdot t \cdot h \cdot \rho_c = 5,38 \cdot 0,048 \cdot 0,6 \cdot 2500 = 387,36kg$$

$$g_{beam} = g_{beam}^{Norm} \cdot \gamma_f = 387,36 \cdot 1,1 = 426,1kg$$

$$q_{beam} = \left. g_{beam} \middle/ l \right. = \left. 426,1 \middle/ 5,38 \right. = 79,2 \, ^{kg}/_{m^2}$$

Total: $q_{const} = q_{glass} + q_{Schuco} + q_{rack} + q_{beam} = 88,4 + 1,8 + 1,8 + 79,2 =$ $171,2 \, ^{kg}/_{m^2}$

    2. Temporary loads:
        A. Snow load:

III snow district; $p_0 = 180 \, ^{kg}/_{m^2}$

        B. Engineering load: $50 \, ^{kg}/_{m^2}$

Total: $q_{temp} = q_{snow} + q_{eng} = 180 + 50 = 230 \, ^{kg}/_{m^2}$

The total load on $1m^2$:

$$q_{total} = q_{const} + q_{temp} = 171,2 + 230 = 401,2 \, ^{kg}/_{m^2}$$

3.2.4 Designing

Perpendicular to the trusses are fixed beams, made of thick laminated glass. Step beams are 1,700 mm. Welded steel beams are fastened the square profile, which is based in glazing, creating a translucent top fence. Double-glazed windows are

placed at an angle to the beams with spiders and different height-resistant steel profiles. (Explanatory note of the project, 2008)
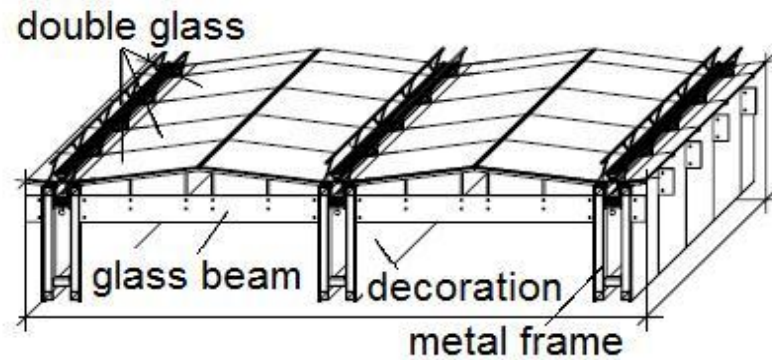

Fig. 3.7 3D model of glass roof

The ordinary supports beams are made of tubular steel truss structures. The span of ordinary beam is 5,380 mm. The height of the beam – 600 mm.
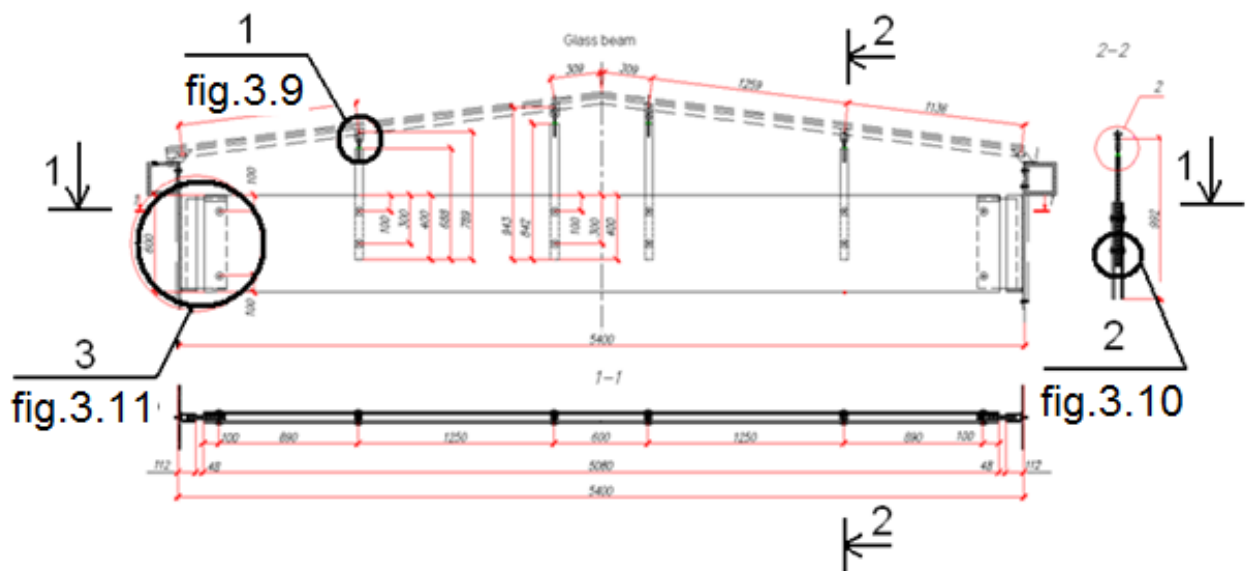

Fig. 3.8 Overall scheme of the beam B1

A beam is a package of four sheets of tempered glass with a thickness of t = 12 mm, bonded together by a point attachment type «Rodan» (Fig. 3.8).
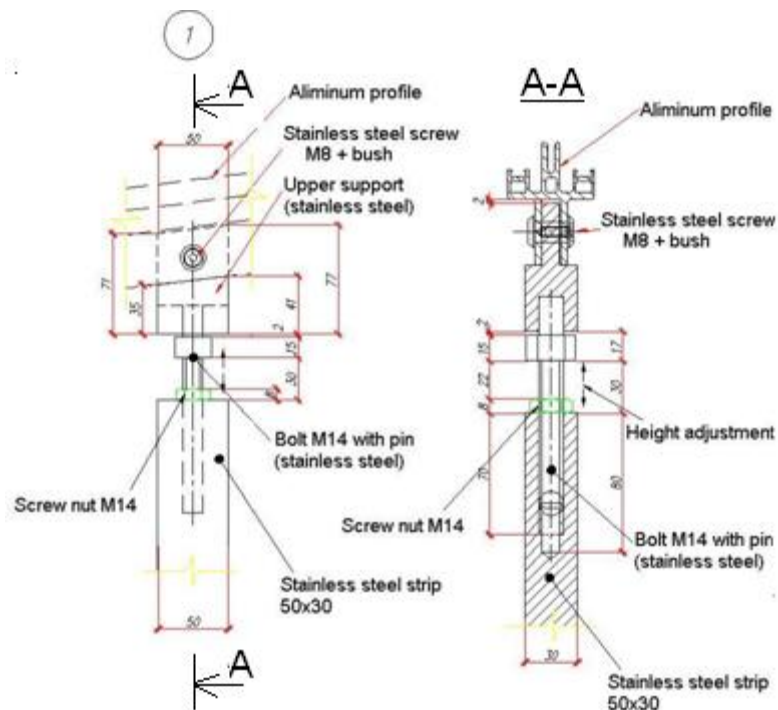
Fig. 3.9 Fastening junctions of glass covering to racks

Steel racks are cross 50x50x4 mm. The scheme of attaching glass components to a metal pendant is shown in Fig. 3.9. A pair of glass with metal parts go through a strip of polymer material HILTI HIT-Y70 with the elastic modulus E = 1750 MPa and compressive strength Rc = 31 MPa. Node pair beams B1 are attacheed to the points as shown in Fig. 3.10.
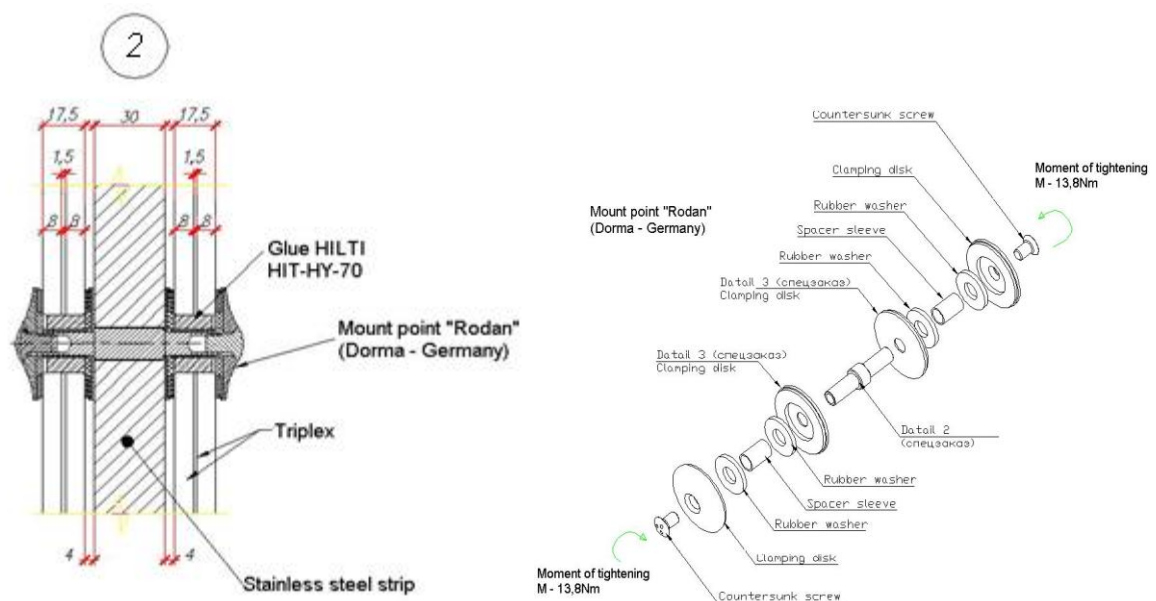

Fig. 3.10 The scheme of klyammer (jointing)

Node interface with support beams B1 bracket as shown in Fig. 3.11. Support brackets, made of 12 mm stainless steel band are based on the metal. (Explanatory note of the project, 2008)
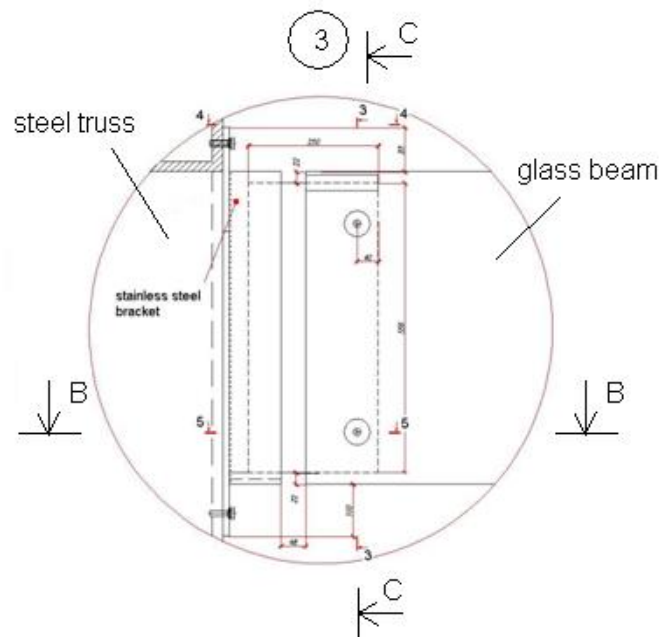

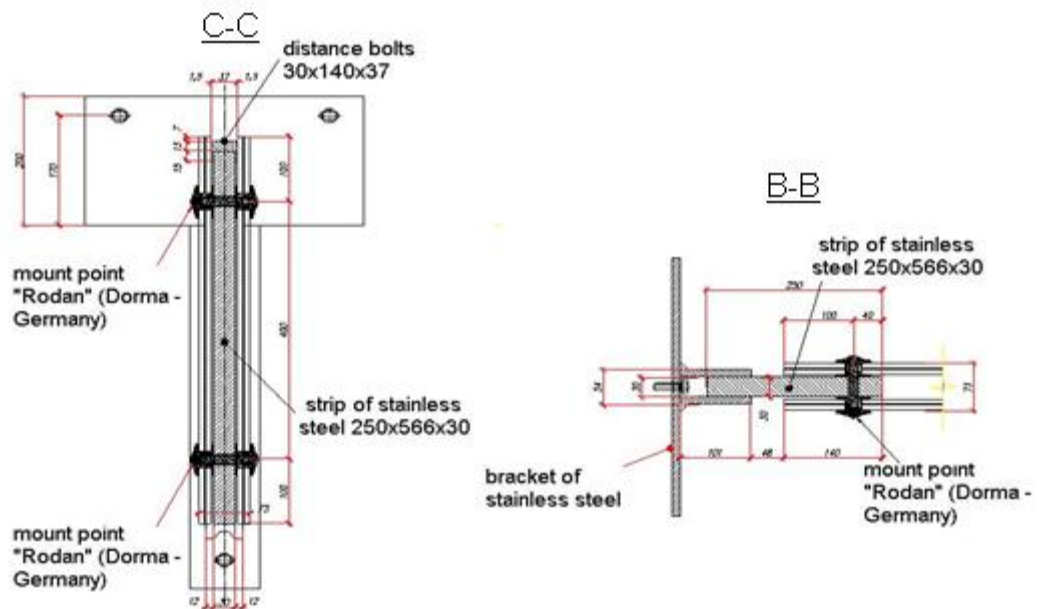Fig. 3.11 The junction of supporting beam B1 on the steel truss

Fig. 3.12 The sections of junction of supporting beam B1 on the steel trusses

3.2.5 The method of calculation in brief

The calculations were performed using the design-computer complex StructureCAD v. 11.1, realizing the finite element method in the form of the method of displacement. The calculation is based on the method of finite elements, using nodes design scheme with a basic unknown displacements and rotations. In connection the this the idealization of the structures are made in a form adapted to the use of this method, namely: the system is represented as a set of standard solid type (rods, plates, shells, etc.), called finite elements and associated to the junctions. The type of the finite element is defined by its geometric form, the rules determining the relation between the the displacements of junctions of finite elements and the junctions in the system, physic law, which determines the relationship between internal efforts and internal displacement, and a set of parameters (stiffness) within the description of the law, etc. (Feodosiev V., 1967)

A along with the usual kinds of influences and pressures, such as its own weight, snow and wind, and also forced exposure (the deformation of the basement) should be notified in the calculations. On the other hand, we should not forget about the strength of glass, the meaning of the multilayer layer of the triplex, as well as environmental conditions and the duration of impact loads. In this thesis the strength, the rigidity and the stability of the series bearing glass structures (beam B1) are analyzed. (Feodosiev V., 1967)

3.2.6 The calculation of glass beam

Diagram B1 is an ordinary glass beam with a 5.38 m length, consisting of four sheets of tempered glass with a thickness of 12 mm. Based on the beam, there are four racks, which hold the filler glazing. The beam is based on a stainless steel bracket. A general view of the finite element models is presented in figures 3.13-3.14. (Explanatory note of the project, 2008)
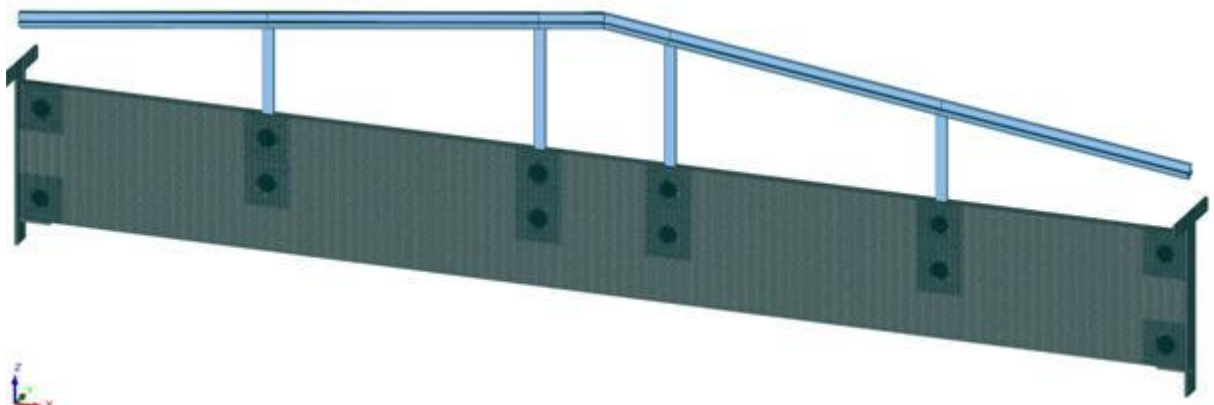
Fig. 3.13 B1. General form

Idealization geometric image was to allocate the main elements of the bearing system of the building, the minimum simplifying their forms and ways of pairing (Fig. 3.13 and 3.14).
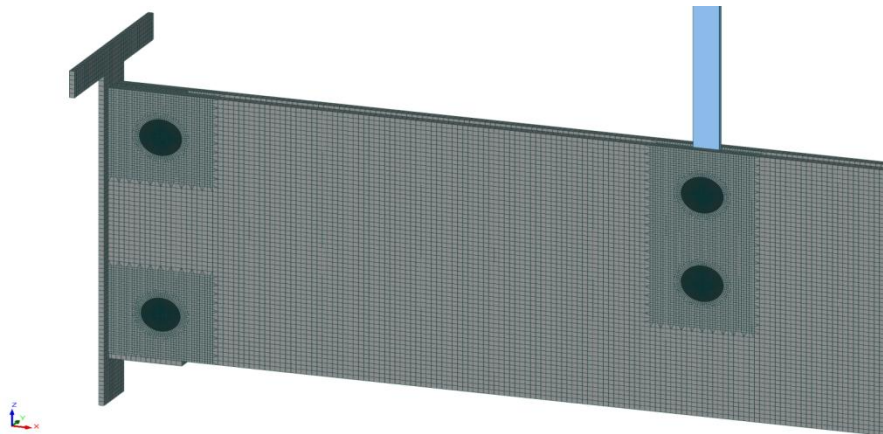

Fig. 3.14 B1. Fragment

Considering the following calculation loading:

№	Name of loading
L1	Estimated load on its own weight of metal elements
L2	Estimated load on its own weight of glass elements
L3	Estimated load on weight of glass covering
L4	Estimated load on engineering using
L5	Estimated load on weight of snow covering

Considering the following combination of loading:

C1= 1*(L1) + 1*(L2) + 1*(L3) + 1*(L4)

C2= C1+ 1*(L5).

In testing, a load transfer at the glass beam must be carried out strictly in the vertical plane. Considering the following options applicable:

V1. The glass beam has strictly vertical position

V2. The glass beam has a deviation from the vertical plane (defects in assembly, the strain of supporting structures, etc.)

3.2.7 Conclusions and references of the calculation

The results of the work for the triplex with a thickness of 8mm glass make the following conclusions:

1. Maximum deflections do not exceed the maximum allowable values:

$$f_{max} = 0.97 \text{ мм} < |f| = \frac{1}{200}l = 25,9 \text{ мм}$$ (SNiP 2.01.07-85* «Load and pressure»)

2. Overall stress-strain state

Maximum principal tensile stress is for:

$$\sigma_1^{max} = 6,37 \text{ МПа}$$

Maximum principal compressive stress is for:

$$\sigma_3^{max} = 7,38 \text{ МПа}$$

Local stress-strain state

A maximum principal tensile stress in the zones of stress concentration is for:

$$\sigma_1^{max} = 4,39 \text{ МПа}$$

A maximum principal compressive stress in the zones of stress concentration is for:

$$\sigma_3^{max} = 13,36 \text{ МПа}$$

The strength of glass panels is assessed in accordance with the theory of maximum normal stresses. (Feodosiev V. "Resistance materials") In the present with the calculated resistance of glass is accepted as follows:

Axial tensile - $R_p = 50,0 \text{ МПа}$

Axial compression - $R_p = 1000,0 \text{ МПа}$

Adopted criteria for general and local strength are used. The maximum utilization of the material under tension does not exceed 0,1275 (Appendix 3).

Given the considerable variation in strength properties and fragile fracture of annealed glass, as well as the incomplete of the existing regulatory base in Russia for the design of load-bearing glass structures should provide:

- conducting mechanical tests designed glass beams cover the full size range of the identification of their limit states for design schemes of loading and fastening;

- computer modeling and analysis of the stress-strain state of structural coverage in the event of local failures of elements.

3.2.8 Tests of glass beams

Estimated design is closely related to testing. The methods of calculations of glass structures can not be discussed independently of testing procedures. In this connection it is appropriate to introduce briefly general quality control procedures carried out in Europe.

Static fatigue tests

Static long-term tests with constant load, which are often called "static fatigue tests", are usually carried out by loading a 4-point bending (4PB). The advantage of such tests is that the test conditions are similar to the operating conditions of construction elements like glass for loading a constant load, for example, its dead loads. The main drawback of such tests - they take a long time. (Haldimann M., 2006)

Dynamic fatigue tests

The term "test on the dynamic fatigue common, is commonly used for an ongoing testing of the load, with a constant checking of pressure and cyclic loading. Mainly by using a 4-point bending or double rings with a single axis (CDR). The latter is also known as concentric rings. The figure 2.21 shows the schematic drawing of the two test systems.
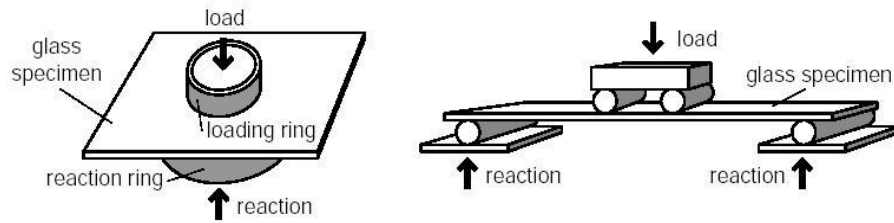
Fig. 3.15 Schematic representation of coaxial double ring (left) and four point bending (right) test setups. (Haldimann M., 2006)

Direct measurement of the growth of large through-thickness cracks

Particularly before measurements on indentation cracks became popular, this experimental approach was used to determine crack velocity parameters. The growth of a large through-thickness crack is directly measured (e. g. optically or using sound waves) as a function of the stress intensity factor. On one hand, this is a direct and relatively precise approach. On the other hand, however, engineers designing structural glass elements are not interested in the behavior of

such large through-thickness cracks. (Haldimann M., 2006)

The skylight for the Yurakucho subway station for the Tokyo International Forum has been developed by Dewhurst Macfarlane and Partners in 1996.

Fig. 3.16 Underground station of Yurakucho in Tokyo

For Yurakucho station tests were carried out at University City in London, where the

specimen was loaded at three points through the holes, but not on the edge. The results showed that the average strength of tempered glass is 160 N/mm^2. From the manual for allowable stress for short-term pressures that can be considered a safety factor of 3. Allowable stress for tempered glass then is 53 N/mm^2. The value is quite comparable with the characteristic values of the voltage specified in Eurocode prEN 13474-1 (in the present tense in development). (Firman Glass)

Tests for the glass failure prediction model

Forecast breakage (GFPM) does not use the aforementioned procedures. There are two interrelated parameters of surface defects and e_m ~k, which are determined by loading rectangular plates with a uniform lateral load. The growth of cracks is determined visually and depends on the intensity factor loadings. On one hand, this method is fairly accurate, but on the other hand, builders are not very interested in the behavior of cracks in the thickness of glass. (Haldimann M., 2006)

In Russia, due to lack of regulations for load-bearing glass, it's necessary to conduct tests. Tests for load-bearing glass beams used to cover the yards of General Staff Building, will be organized at CRIBS Kucherenko (Central Research Institute of Building Structures) in Moscow. A stand is designed for tests, shown in Figure 1. The stand consists of a base (pos.1), which is established with a the vertical rack space (pos. 2). On the vertical posts a beam (pos.3) is installed as well as a power element designed for mounting the mobile traverse (pos.4). Moving the traverse is made at the expense of rotational motion of elements - tenders (pos.7) is strictly on the vertical axis through the guides. Vertical rails are installed through bush bearings. Before the test stand is set in a horizontal position running devices (pos.5). With a screw pair (pos.6) the facility is set in vertical position and fixed on the vertical rack (pos. 2). (Explanatory note of the project, 2008)
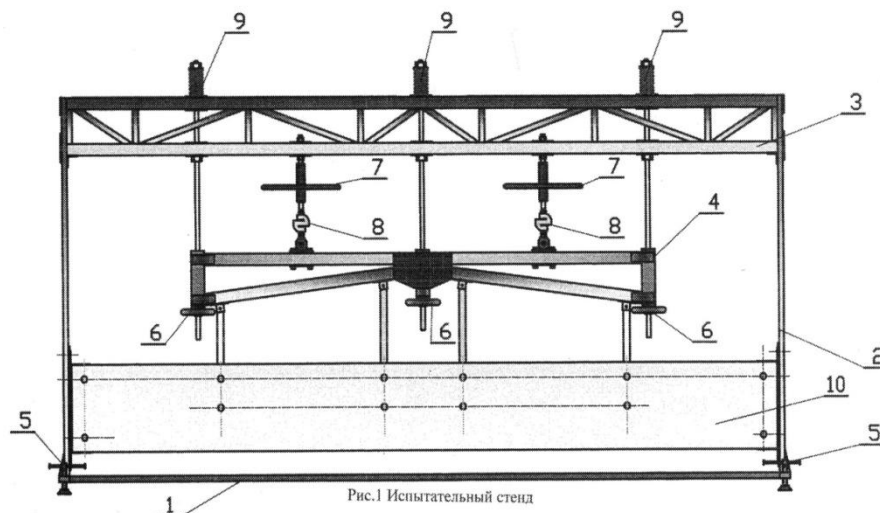
Figure 3.17 Test sample of beam

When coupled with the rotation of tenders the test item is loaded with uniform load. With the release of one of the tenders the test model is loaded with unevenly loads. Working with tender communications (pos.6) are exempt and they act as guide elements. On the rails in the upper part of the beam installed spring (pos.9) is installed to allow shock loads in the upright position. Structural stability against overturning tilt braces spatial supports racks (pos. 2). The test standard done on a beam of glass span 5.38 m (fig. 3.8), consisting of 4 sheets of triplex sized 600x12 mm, connected elements - layers made of polymer material of the company «HILTI» HIT-HY-70, 4-metal elements, bearing steel elements. (HILTI, 2009)

The test of models will be scheduled for uniform and unevenly loads. The intensity of the estimated load is taken to be 322 kg/m^2. The load will be laid in phases. After reaching the load, endurance is needed during a day. In the process of testing a to test system on to test the impact of shock load applied to the center of the beam in vertical and horizontal directions. By planned checking the bearing capacity of the test specimens the load capacity will be ensuring excess of the calculated load by 25%. (Explanatory note of the project, 2008)

To determine the parameters of the stress-strain state of a glass beam under load values of the strains in the sections indicated on the scheme will be obtained. Marking sensors include the section number, the number of plane glass sheet of the

41

beam, the number of sensors (sensor is 3-1-5 in section 3 on the section has the number 2 and has №5). The placement of strain gauges are made in sections with alleged, most normal and tangential stresses, as well as in sections with stress concentrators. The sections with the maximum normal stresses are:

– with a uniform load - in the center of the span beams

– unevenly load - a quarter of the span beams

Sensors to determine the strain are placed on the most stressed fibers of the upper and lower sections, on all four sheets of glass beams. Places with stress concentrators are in the areas surrounding the holes. There are two openings in the span zone – four in half of the beam in the reference area. To measure the strain in sections adjacent to the openings, three sensors in 2 sheets of the beam are installed. In the core zone and in the zone located close to a quarter of span sensors are located on the outer glass sheets of the beam, and in areas with holes that are closer to the center span - internal sheets. (Explanatory note of the project, 2008)

3.4 Metal load-bearing structures

The initial draft of the reconstruction of the General Staff using glass beams, but the building is being replaced by steel trusses due to the high cost of manufacturing, transportation and installation. Steel trusses are installed in places that the glass beams (Fig. 3.18). (Explanatory note of project, 2008)

Figure 3.18 The plan of steel trusses

Standard beam length of 5,380 mm consists of curved square profiles of 50x25x4 mm and with a height of 450 mm with coated facing material on three sides. Frameworks facing the beam are attached with the support of the transition from metal fasteners. Supporting pattern-glazed windows and counters are done according to the same principle as in the glass beams. (Explanatory note of the project, 2008)
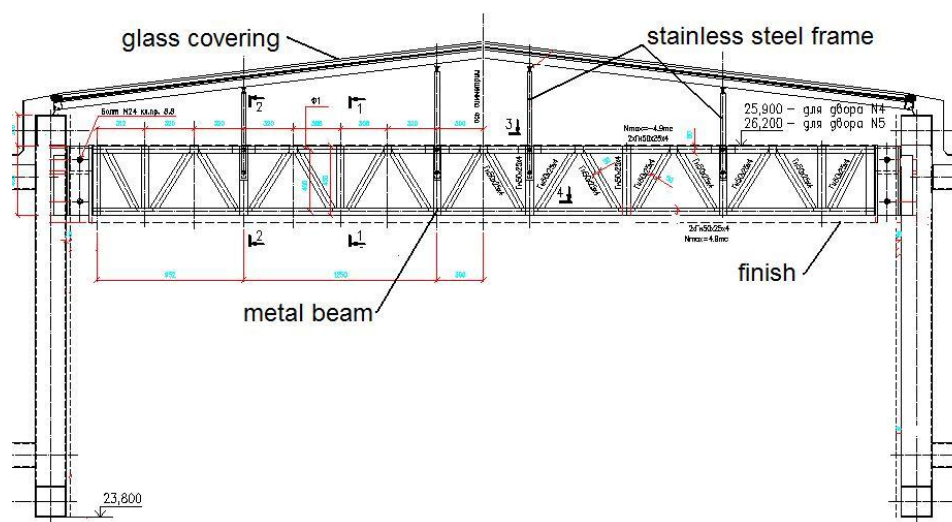

Figure 3.19 Steel truss

The design of steel trusses is calculated for strength and stability by design-computer complex StructureCAD v.11.1, which implements the method of finite elements in the form of displacement.

3.5 Cost of project

The reconstruction of the East Wing of the General Staff started in 2008. The first phase of the project is financed from the federal budget (51%) and with a World Bank loan. An estimated cost in comparison with the original will be redefined due to the global financial crisis and the replacement of glass beams with steel trusses (an average cost of glass beams are 4228,4 rubles per square meter). (Consolidated construction cost estimate, 2007)

The reasons for rejecting the use of glass beams in the structures of translucent cover the first phase of the construction are:

43

- A glass product is two or three times more expensive than similar items from indigenous materials, due to the high cost of production and processing of glass.
- Prices depend on several factors. The thicker the glass, the more expensive it is.
- Frosted glass is also more transparent, even more expensive if it is toned and colored.
- The price increases according to quenching (approximately 20%) and the complex shape of the product: in rounded forms, it will be 10-20% more expensive. (Glass Center, 2010)

According to the Loan Agreement, signed in July last year, the implementation of the first phase of the project allocated 4.4 billion. According to foreman, the project has been full of unpleasant surprises. For example, the condition of the building after the removal of all layers of plaster was worse than expected, the windows in the building were of one hundred and fifty sizes, almost all different from each other. All this required additional work and increased the cost estimate compared with the original.

In the competition for the second consecutive stage five companies were involved. Applicants for the role of general contractor of the second stage have been prequalified. The results have been sent the World Bank to Washington. The contract with the contractor on the results of the tender will be signed in June. The contract price for the second stage will be higher than for the first, as more expensive restoration work is required. According to Nikita Yavein, the amount of the contract could reach 5.5 billion rubles. A part of the work that should have been done in the second stage of the project, was included in the first phase. This included the monitoring of the surrounding buildings (and the Alexander Column), as well as strengthening the foundations of the building, the first and second, to strengthen a separately proved risk, as they are linked (Explanatory note of the project, 2008)

5 CONCLUSIONS

As a constructional material the glass has been used throughout the world for more than one millennium, but as a load-bearing element of construction it has been the open only in the last century. In my thesis there are a few known examples of glass as a load-bearing element, which can form the basis for the design of such structures. Here was presented the main developments in the construction documentation in Russia, Europe, Canada and America, which proves a great need in the overall development of all branches of engineering, architecture, building physics, materials science, etc. In a modern building used a variety of constructions is used and they have their preferred areas of application in accordance with their capabilities and features. But there are many areas in which the various constructions vying with each other and the choice of one or the other of them is faced by a technical and economic challenge. As for the theory of constructive forms and the theory of structures, they are essentially the same for all building structures, although each of them has its own characteristics.

Considering and assessing the world experience of glass designs, architectural workshop "Studio 44" designed a version for a translucent cover structures of courtyards of the East Wing of the General Staff Building. In my thesis translucent cover of glass beams was calculated. With the help of this thesis one can conclude about the use of glass structures as load-bearing elements.

In the design of any structures it's necessary to comply with a number of requirements. All requirements can be divided into several groups: the purpose, technical, technological, operational, economic and aesthetic. They are very important. Most of them must certainly be fulfilled, primarily the purpose and technical requirements.

The design should at its best serve its purpose, the maintenance of a process that must take place in the projected building or a facility. For example, if it is a circus, you need to take into account that suspended piece of equipment you need to have a certain height and so forth, and so in each facility. Technical requirements - certainly

providing strength, stability (shape and location, as well as local stability) and rigidity. These requirements are determined in a SNIP design. This is also the reliability requirement, or, in other words, the design must work flawlessly within a predetermined period of operation of calculation. In fact, throughout this period strength, stability and rigidity in the light of the accumulated defects - deflections, corrosion, etc must be provided.

The design should be technological, the should be considered to easy manufacturing, transportation, installation. You have to think about comfort and work performance, especially in the installation. After the design has to be mounted in heat and severe frost. A convenience often depends on the type of connection, junctions and other dimensions. The design should take care of the technological exploitation. Because the design should prevent damage and corrosion. This is also included in such a requirement as maintainability. Already at the design stage is necessary to think about the time the design needs to be reconstructed and in some cases strengthened. It should be borne in mind that the physical life (the actual period of its "life"), is 3 to 7 times longer than the moral life, the period originally specified in the process.

Economic requirements are complex - it is first necessary to save metal, to save labor costs at all stages, to save energy costs. Hence it is important to analyze metrics such as metal, energy and labor input. A comprehensive performance value "in" and reduced expenditures in a market economy must not include profit. Then they reflect the cost-effectiveness of specific structural forms. Do not forget about the conservation requirements in the manufacture and assembly. Finally, we need to worry about the aesthetics of design, its beauty and harmony. It should be noted that the designed rationally design, as a rule, delights the eye with its lightness and beauty.

At the design phase any materials should be considered in the context of the particular design with its advantages and disadvantages. Glass is not exception to this rule.

The advantages of glass:

1. The use of glass in construction work adds beauty to the building;

2. By using glass in interior, it saves the space inside the building;

3. Glass cladding in building fulfills a functional requirement of lighting, heat retention and energy saving;

4. Using toughened glass you can get a high load-bearing capacity;

5. Glass is a good heat conductor, thereby heating the air inside the building by solar energy. The usage of foil blinds allows to keep if naaded to completely eliminate the heating of the building for a long time;

6. When using special layers it reduces the probability of injury from the fall of sharp glass shards;

7. Lighting due to the large area of glazing is natural, gives significant power savings;

8. From the psychological point of view, natural light has a positive effect on the livelihoods and on human efficiency;

9. Tempered glass has a high fire resistance.

The disadvantages of glass:

1. Glass is a very expensive material, it may increase the budgeted cost of construction work;

2. The usage of glass also enhances the cost of security;

3. The usage of glass increases operating costs;

4. Due to the brittleness of the material it is difficult to transport it from the place of manufacture to the point of use;

5. The glass is also unsafe for areas prone to earthquake;

6. The lack of comprehensive data of construction documentation entails the usage of expensive tests;

7. Possible condensation between the sheets of glazing;

8. When the temperature diffes, there may be the phenomenon of thermal shock;

9. When using glass in covering it is necessary to remember about smoke and fire;

10. The structures require high-quality work throughout the supply chain - from the manufacturer to the builder.

After analyzing the advantages and disadvantages of glass as a load-bearing element "Studio 44" has come to the conclusion of the possibility of using glass coatings for courtyards of the General Staff Building. The first phase of reconstruction of Staff Building has the aim to preserve the historical value of the building assuming the usage of glass beams, but due to insufficient financing the decision was made to the use steel trusses. At the moment steel is widespread used for the construction of production facilities for heavy industries, bridges and other important buildings. This reconstruction project was not exception, which is highly regrettable, as the General Staff Building of the museum and exhibition complex Hermitage is a trademark of Saint-Petersburg.

There is little doubt that the recent and future innovations in glass engineering will improve the performance and will continue to extend the domain of what is possible. Currently, regulatory documentation is under development, which greatly complicates the design of load-bearing glass structures. There is a need to optimize and to bring the documentation in compliance with the requirements of modern design. Recent developments in societal needs and technology are creating unprecedented challenges and opportunities in the use of glass in buildings ranging from complex geometry to occupant safety and lightness/transparency to energy efficiency in buildings. The challenge for design engineers and architects is to select and adopt these technologies not as fashionable add-ons, but at an early design stage when decisions have the largest impact on the final design, thereby leading to optimized performance-based buildings.

FIGURES

TABLES

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List of main architects and designers:

1. Main architects:
   Yavein N. (head of the workshop "Studio 44")
   Elovkov E. (main architect of the project)
2. Main disegner:
   Gerchtein V. (main designer of the workshop "Studio 44")
   Kresov D. (main designer of the project)
3. Fire consultant:
   Pechkov F. (LLC"Center fire and technical expertise")
4. Engineering sections:
   Gyrevich A. (Company "Petroengineering")
5. Manufacturer of glass beams:
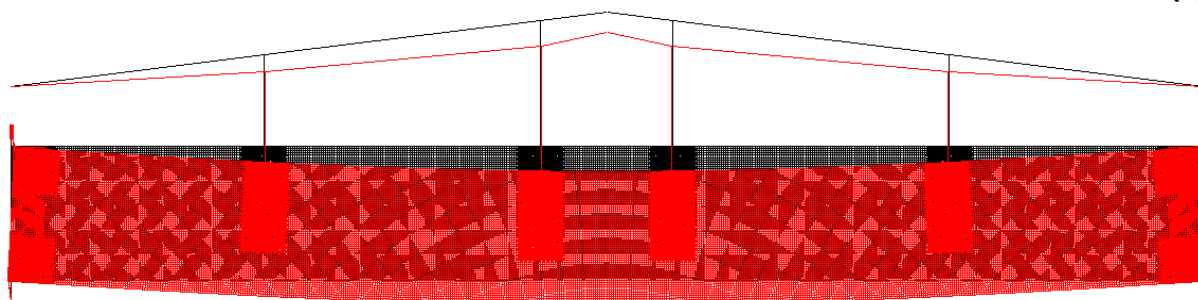   Assotition "TEMP"

SITE LOCATION PLAN

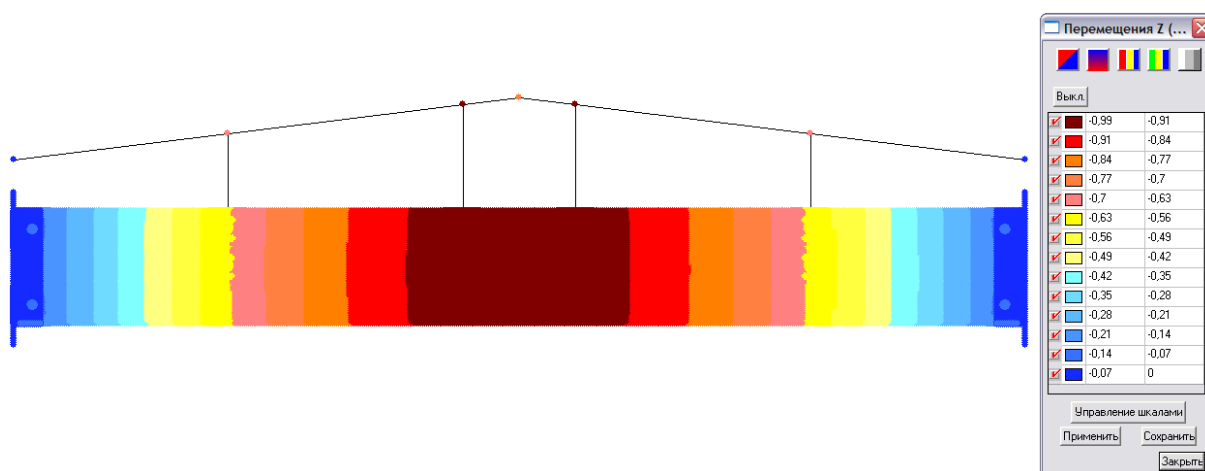СХЕМА РАСПОЛОЖЕНИЯ СТРОИТЕЛЬНОЙ ПЛОЩАДКИ
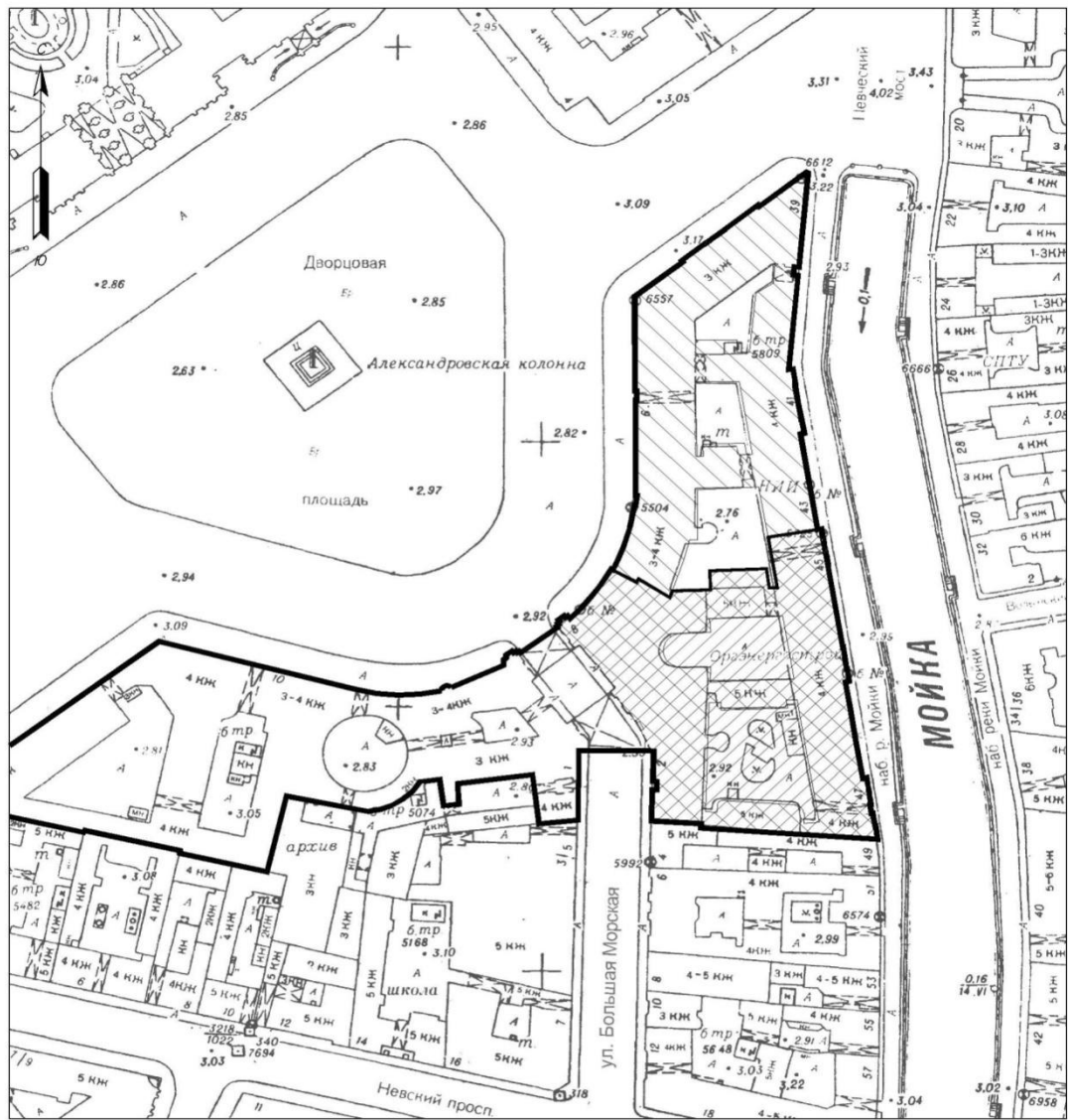
LEGEND / ОБОЗНАЧЕНИЯ

Former General Staff Building
Здание бывшего Главного Штаба

Eastern wing
Восточное крыло
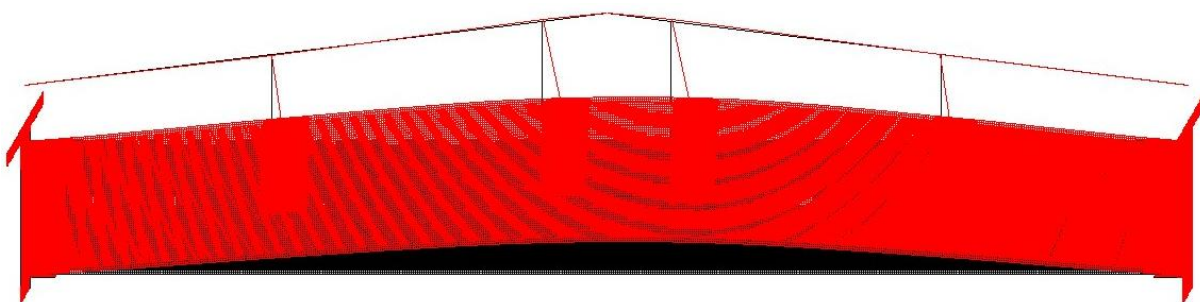
Phase 1 constraction site
Первая очередь строительства

Deformed scheme

Deflection, mm

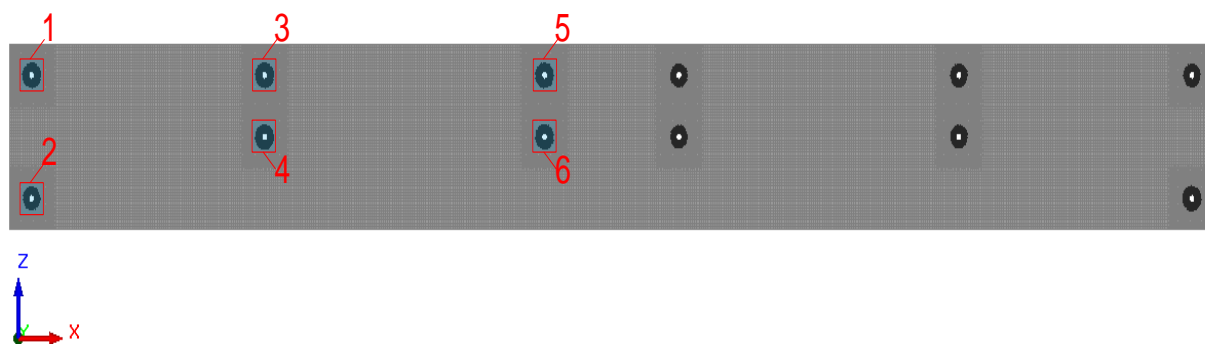Form of stability loss. General form

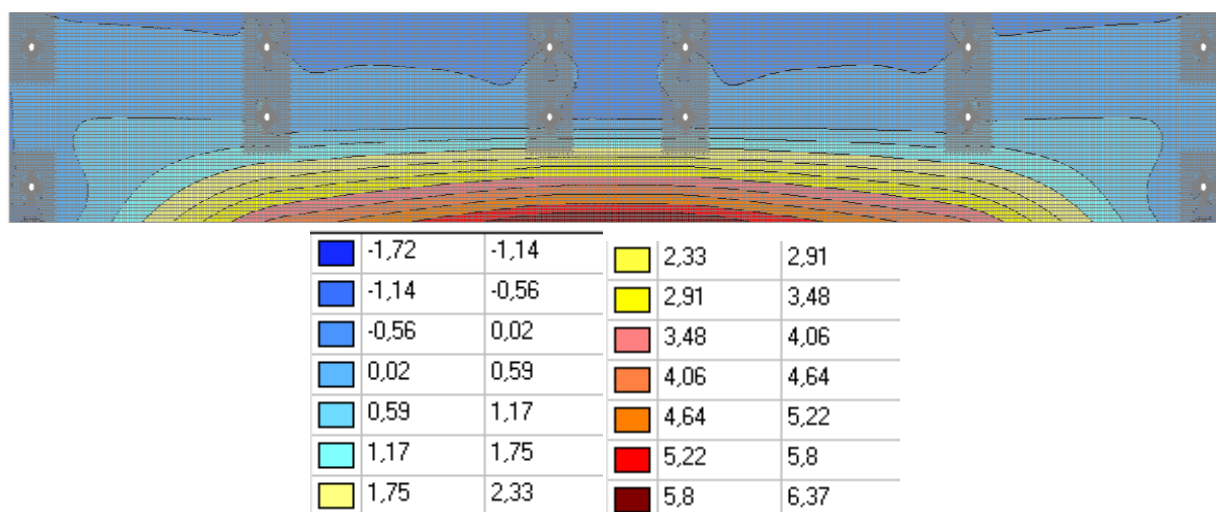Form of stability loss. Projection onto the plane XOY

The numbering of the holes
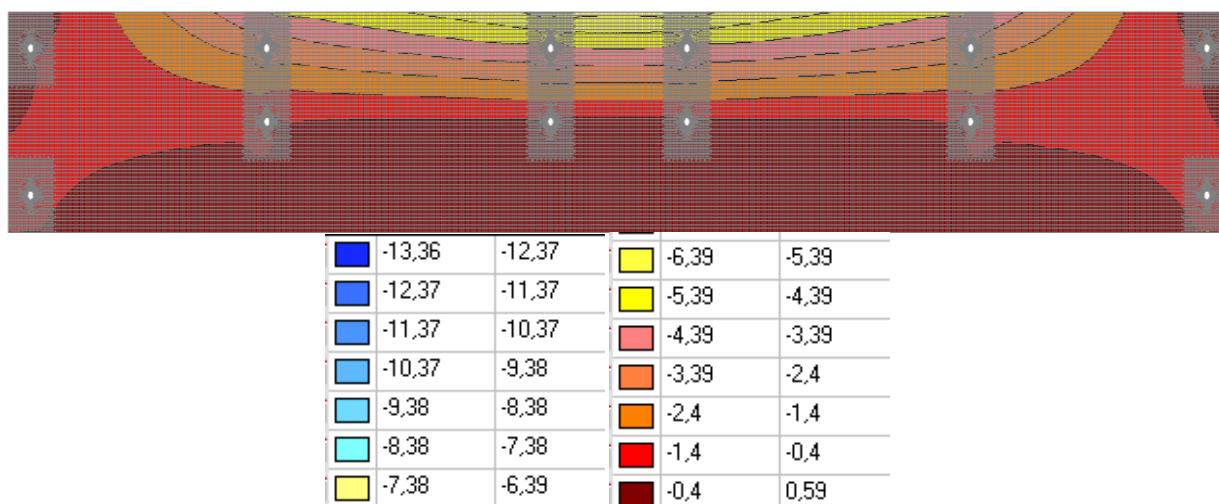

-1,72	-1,14		2,33	2,91
-1,14	-0,56		2,91	3,48
-0,56	0,02		3,48	4,06
0,02	0,59		4,06	4,64
0,59	1,17		4,64	5,22
1,17	1,75		5,22	5,8
1,75	2,33		5,8	6,37

The principal stresses σ₁, MPa

-13,36	-12,37		-6,39	-5,39
-12,37	-11,37		-5,39	-4,39
-11,37	-10,37		-4,39	-3,39
-10,37	-9,38		-3,39	-2,4
-9,38	-8,38		-2,4	-1,4
-8,38	-7,38		-1,4	-0,4
-7,38	-6,39		-0,4	0,59

Principal stresses S₃, MPa