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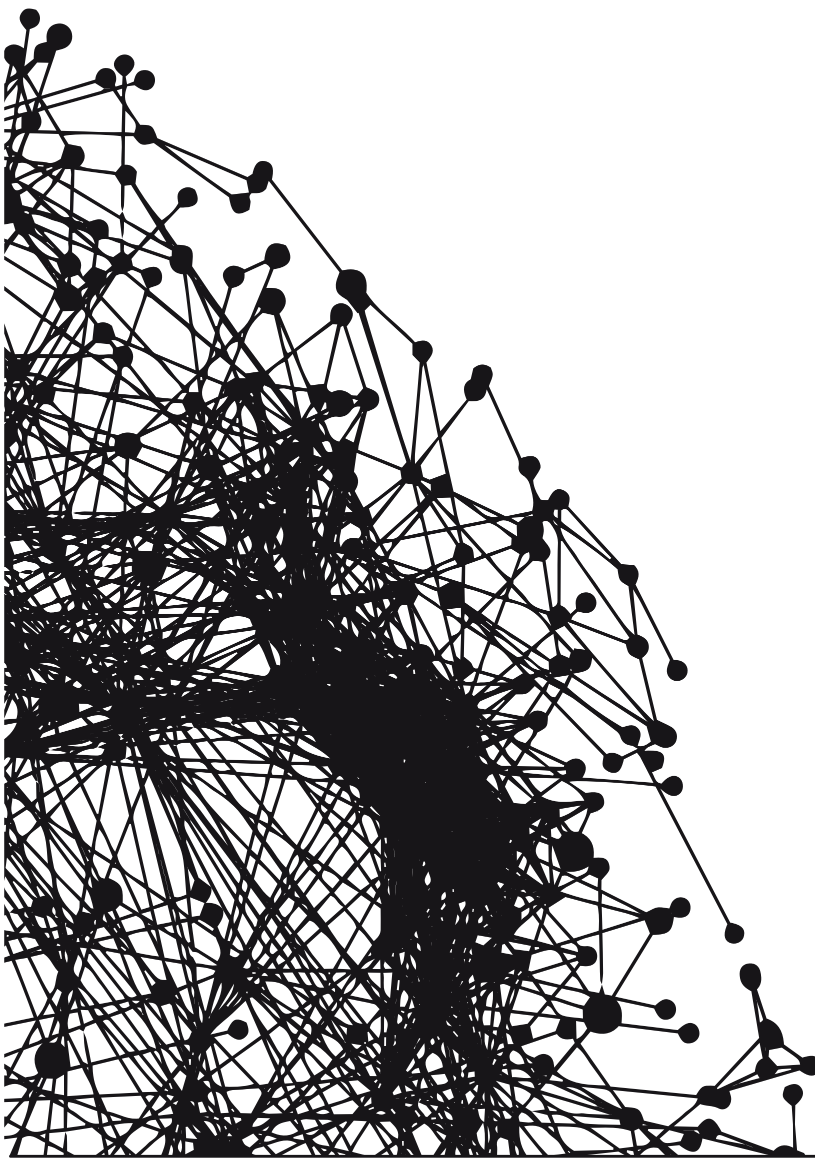

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INFLUENCE OF GLASS COMPONENT JOINTS ON THE STRUCTURAL GLASS FACADE DESIGN

Aleksandra Krstic-Furundzic
Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, akrstic@arh.bg.ac.rs

Tatjana Kosic
Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, tkosic@arh.bg.ac.rs

Jefto Terzovic
Faculty of Architecture, University of Belgrade, Bulevar kralja Aleksandra 73/II, jefto@arh.bg.ac.rs

ABSTRACT

There is a strong relation between the type of glass components connection and the structural glass facade design. The objective of the paper is to study the different solutions of the design of the connections between elements of structural glass facades. Influenced by the load, in relation to the structural system, glass layer may be exposed to different types and intensities of stresses, which inevitably affect the design process in terms of selecting the type and dimensions of glass elements. In order to evaluate the impact of design of component joints on facade structural system and hence its design, some hypothetical models of structural glass components joints are created and numerical analyzes are carried out. Methodological approach entails three steps: creation of typology of joints which includes form and assembly types, design of hypothetical models of structural glass facade components joints and examination of structural stability of hypothetical models.

Keywords: Structural glass, Form types, Assembly types, Structural system concept and stability

INTRODUCTION

The objective of the paper is to study the influence of glass component joints on the structural glass facade design. Facade design includes the design of different types of connections which characteristics influence the concept of the structural system. The paper is intended to serve as state-of-the-practice summary regarding connection types of structural glass facades and in that sense the paper is structured. The typology of structural glass component connections is based on the fact that the interdependence of structural glass component types, connection place and technology type is crucial. Based on connection type, structural system concept and stability of facade structural glass panels are analyzed. The diversity of structural glass panel connections is the potential for different options of facade transparency and building appearance.

Methodological approach entails three steps:
- creation of connection design typology,
- design of hypothetical models of structural glass panel connections and
- examination of structural stability of hypothetical models.

The design of hypothetical models is carried out according to defined connection types. Stability of glass panels in relation to various connection types (linear - with metal or glass sections and dotted - adhesive), is examined through stress and deformation analyses.

"The brittleness of glass presents a major challenge when connecting glass construction components. Connection techniques should be based on a glass-conscious 'construction kit' of various solutions designed to suit different stress conditions, which can be combined and modified. In all cases there must be a uniform loading transfer between glass and connecting elements which has a great effect on the stress distribution in brittle glass" (Wurm, 2007).

The paper is indicating various approaches to design of connections of structural glass facade panels and might be helpful to architects and engineers.

Connection design typology

Considering the connection types in the case of structural glass facades, the following options can be recognized:
- glass components connections and
- glass and other structural components connections,

which determines specific conditions in sense of component types and materials, connection place and technology.

In case of glass facade components mutual connection, classification can be specified according to:
- glass facade component types (connections between linear components, linear and plane components and plane components),
- connection place (at the corner, along the edges and within the surface) and
- connection technology (dotted – bolted and linear - adhesive, with metal sections) as shown in Figure 1 (Krstic-Furundzic et al., 2012).

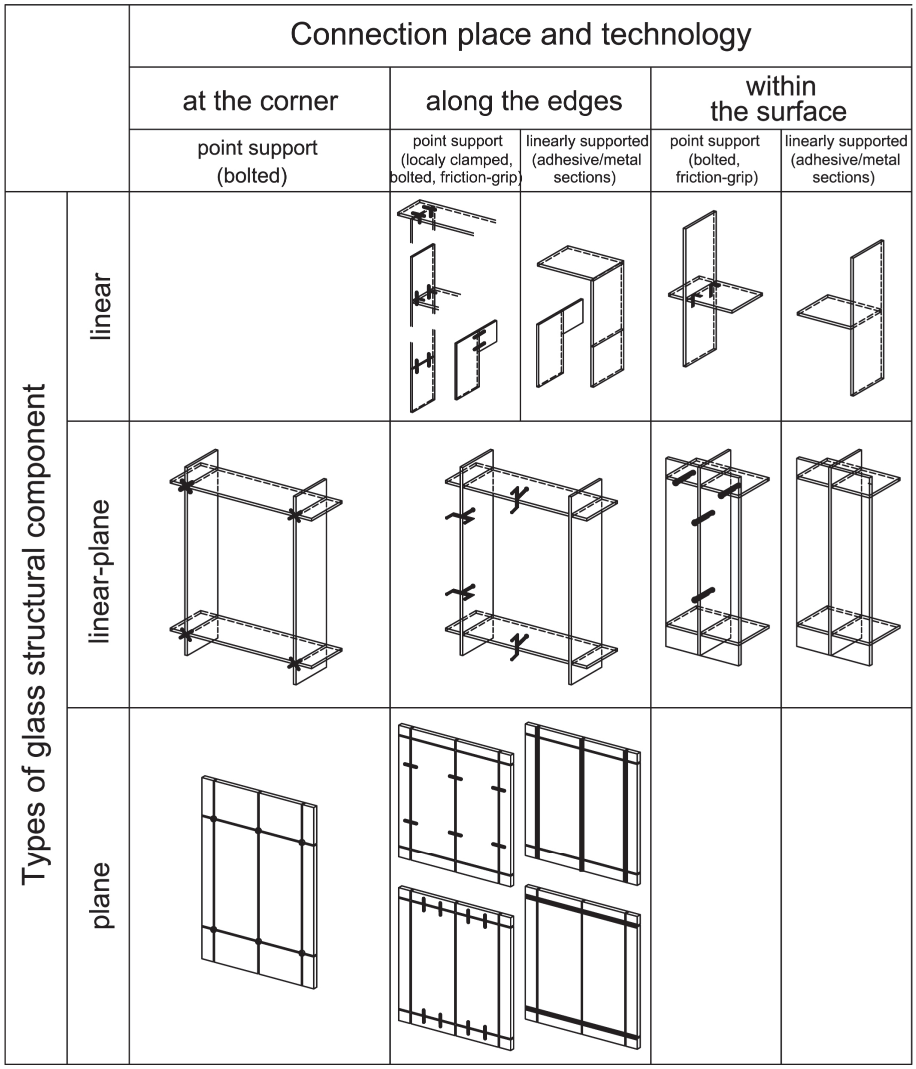


Figure 1. Structural glass facade components connection types.

Also, construction of structural glass facades includes design of glass and other structural components connections which can be classified according to structural components type (connection with the roof, connection with the foundation and connection with the gables) and according to component material (glass and concrete, glass and wood and glass and metal).

Design of hypothetical models of structural glass panel connections

Selection of connection type between glass facade panels and building structure, respectively supporting facade substructure, directly affects the static system of glass facade panels, and still affects the form and visual identity of the facade (Table 1). Connection of the glass facade panels with building structure is enabled by the facade substructure, which, in a static sense, for the glass panels represents linear and point supports. In that sense the following hypothetical models of structural glass facade panel connections are selected:

1. Linear connection - visible or embedded-invisible horizontal sections (Fig. 2);
2. Dotted connection (Fig. 3);
3. Linear connection with frame:
   a) visible sections (Fig. 4a),
   b) embedded horizontal sections and visible vertical sections (Fig. 4b).

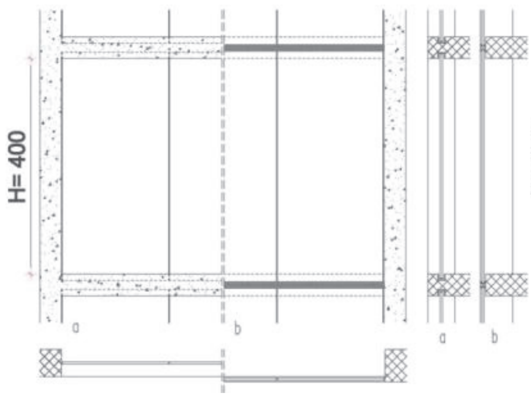


Figure 2. Glass panels supported by horizontal sections (embedded-invisible or visible).

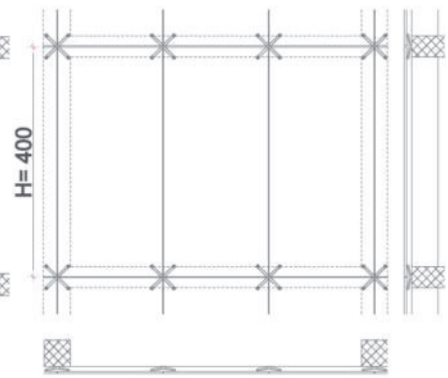


Figure 3. Glass panels supported by point joints.

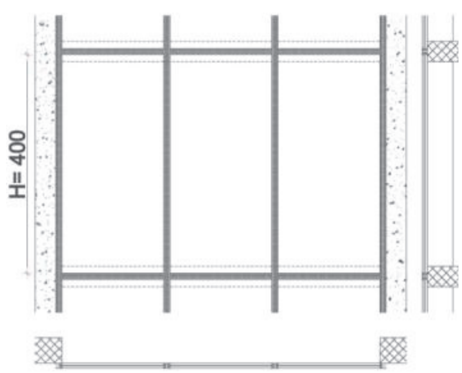


Figure 4a. Glass panels supported by frame (visible).

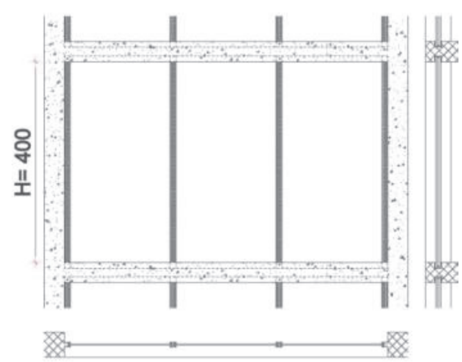
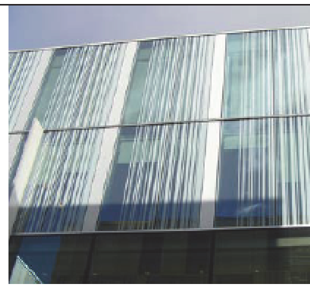
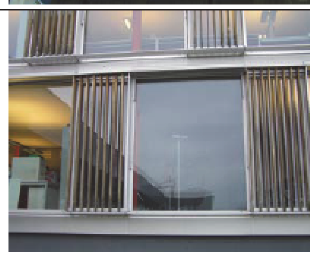
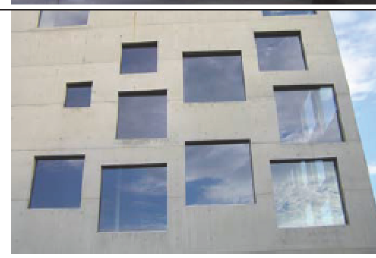
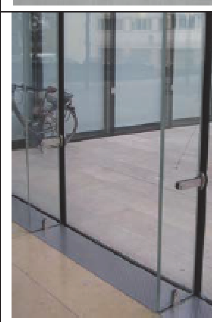
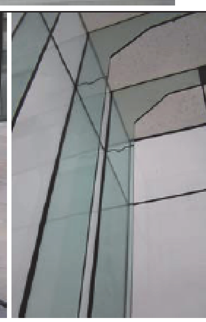
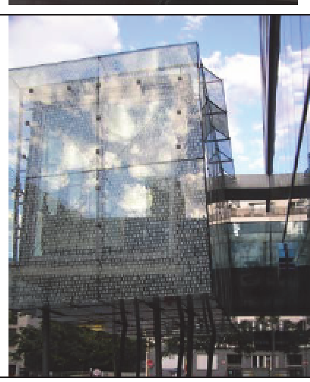


Figure 4b. Glass panels supported by frame (visible vertical and embedded horizontal sections).

Table 1. Connection type and visual identity of the facade (Photos: A. Krstic-Furundzic)

	Visible sections	Embedded-invisible sections
Glass panels supported by horizontal sections		
Glass panels supported by frames		
Glass panels supported by vertical sections		 
Glass panels supported by point joints		

INFLUENCE OF CONNECTION TYPE AND FACADE DESIGN ON THE STATIC SYSTEM OF THE STRUCTURAL GLASS FACADE PANELS

With the different variations of number of supports and their mutual arrangement, the system provides a variety of connection options for the design of glass facade panels in terms of shaping and material consumption. The computer models of facade glass panels of 2 m wide and 4 m height, which are loaded by wind force perpendicular to its plane, are created and analyzed. In models, various panel supports were combined: linear supports only on shorter opposite edges (relying only on the floor structure); point supports on the panel corners (spider facade); and linear supports throughout the whole scope of the panel (relying on the floor structure and vertical load-bearing elements of the facade substructures). Each of these support conditions can be clearly read out on the facade in terms of design, and it shows a direct connection of the structural system of the facade and its visual identity.

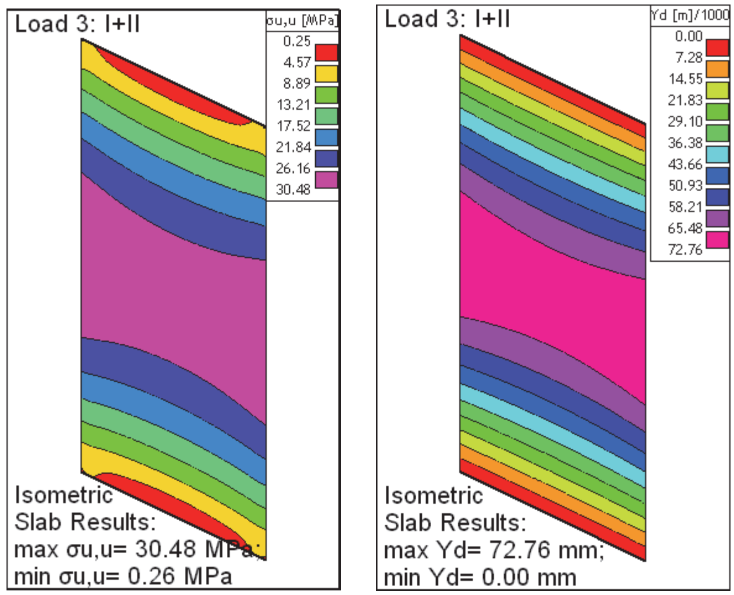
The analysis was done by software Tower 6.0 (www.radimpex.rs), based on the Finite elements method which is an assemblage of many mathematical entities (finite elements) as an approximate representation of geometry, material properties, connectivity, and their spatial relationships. In computer model, glass elements are designed according to its characteristics which are described by adequate Module of elasticity, volumetric weight, Poisson's coefficient, thermal coefficient (Krstic-Furundzic et al., 2013).

Static analysis – computer models

Glass facade panels rely on a support building structure, usually on the edge of the floor structure, through elements of the facade substructure. In case of linear (continuous) facade substructure elements connected to the building structure, they stand negligible stress and all the external load is transferred on the floor structure of the building through shear force in the cross section of fasteners (bolts, anchors) by which the elements of facade substructures are attached to the building structure.

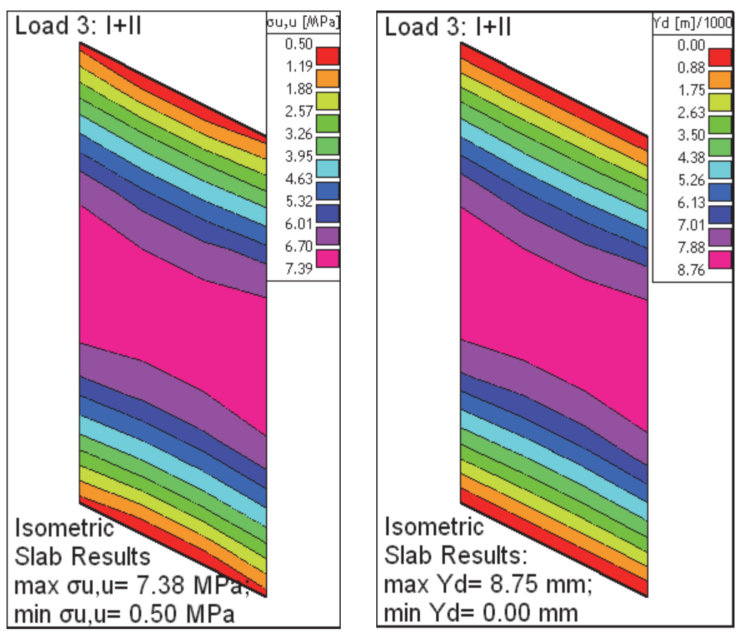
In case of such reliance when vertical grid elements of facade are omitted, the facade glass panel corresponds to the static system of simple beam. This panel acts as orthotropic plate carrying in only one direction, since its two edges are free and do not have any contact with facade substructure or the building structure. The span of the facade panel, which is linearly supported by a horizontal edge, consequently, is equal to the floor height of the building.

In the first case, the flat panel of 20 mm thick toughened glass, linearly supported on horizontal edges (Fig. 2), is analyzed. In the computer model, which takes into account the glass panel net weight (load case I), the equally divided surface load of intensity of 1.00 kNm^2 (load case II), simulating wind effect, is applied. The results show that the stress is within the allowed limits, but the deformation is unacceptable because its value is much above permissible limits, as shown in Figures 5a, b.



a) b)

Figures 5a, b. Normal flexural stress (a) and deformation (b) of the flat glass panel of 20 mm thickness, linearly supported on their horizontal edges to the floor structure (story h = 4 m).



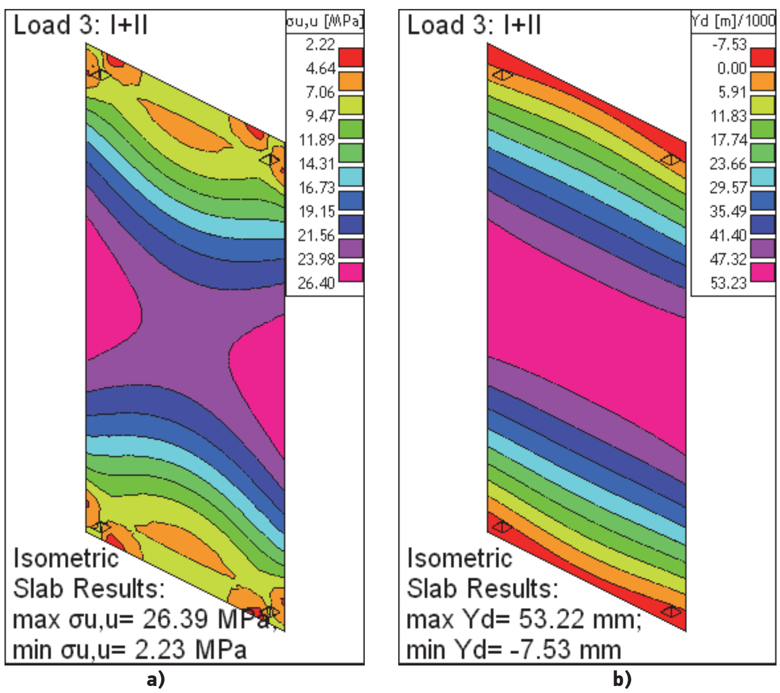
a) b)

Figures 6a, b. Normal flexural stress (a) and deformation (b) of the flat glass panel of 40 mm thickness, linearly supported on their horizontal edges to the floor structure (story = 4 m).

Acceptable deformation results, for the same story height i.e. span of the glass panels and the same load conditions, are obtained only by using a double-thicker laminated glass panels (40 mm), as shown in Figures 6a, b.

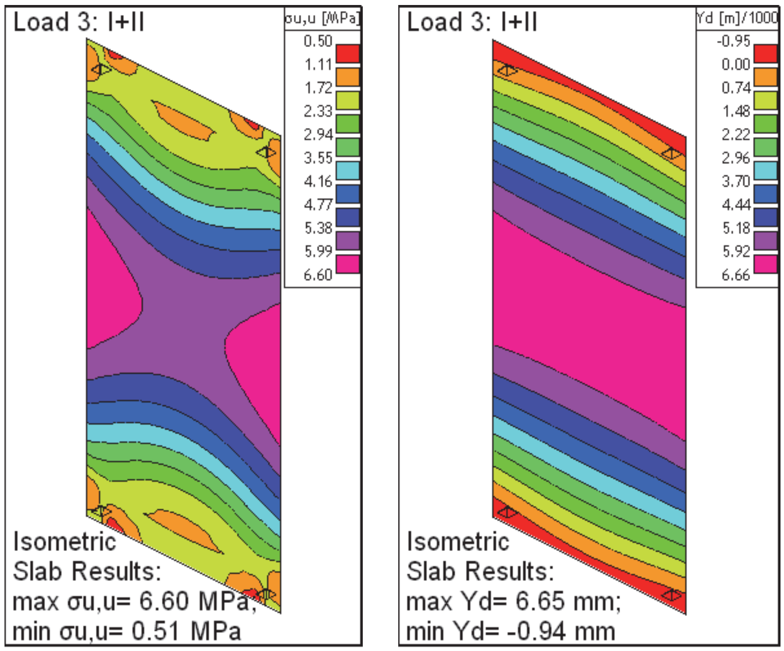
This case of support conditions of the facade glass panel shows that avoiding vertical elements of the facade substructure, respectively avoiding the vertical division of the glass facade surface using metal or glass substructure grid, dramatically affects the use of material - glass.

The pane or plate structural glass elements can be supported on their edges, corners or surface at points. The form of loading transfer has a great effect on the stress distribution in brittle glass. Point or unevenly distributed load transfer produce concentrated load effect and do not make efficient use of the glass cross section. The stress at the support points can be up to three times the general stress level, making it usual to have to use thermally treated glass and more complex design of the support points (Wurm, 2007). For the purpose of this research, the model of the panel with support points located in the corner areas of the glass panel is created (Fig. 3). Due to the fact that support points are placed on certain distance from the panel edge, thereby forming the static system of beam with minimal overhangs on both sides, as well as due to reduced span of beam, stress and deformation values are less than in the previous case - the panel linearly supported on horizontal edges, as shown in Figures 7a, b.



Figures 7a, b. Normal flexural stress (a) and deformation (b) of the flat glass panel of 20 mm thickness, supported at points on their corners to the floor structure (story height 4 m).

By applying point supports in corner areas of the 20 mm thick glass panel, which are directly connected to the building structure, still cannot get satisfactory results in terms of stress and deformation. In order to achieve the value of deformation within the allowed limits, it is necessary to increase the thickness of glass panel (40 mm), as shown in Figures 8a, b.

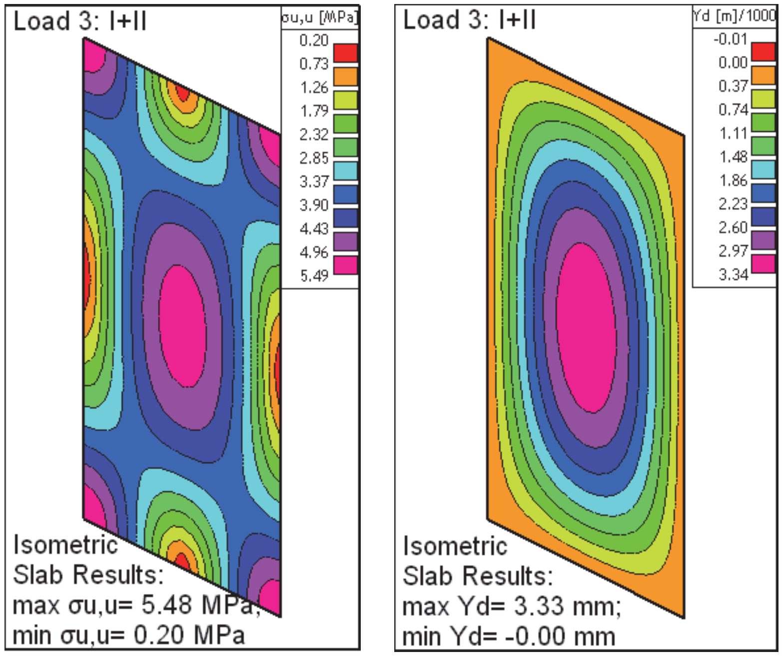


a) b)

Figures 8a, b. Normal flexural stress (a) and deformation (b) of the flat glass panel of 40 mm thickness, supported at points on their corners to the floor structure (story height 4 m).

In the case new support points are arranged at the half the height of panels, stresses and deformations would be reduced to minimum. However, this requires setting the vertical element of facade substructure in order to set up the point supports at the middle of the story height.

Using vertical elements of substructure, which are in static sense the linear supports, enables facade glass panels to rely throughout the whole scope of the panel forming the static system of a plate that carries in two orthogonal directions, whereby the direction of the shorter span is more burdened. If the distance between the vertical elements is smaller than story height and there is no horizontal division of glass facade surface, the horizontal direction is the direction of the dominant strain of the glass panels. In this case, vertical substructure elements are the main linear panel supports forming the static system of a simple beam and need to be specially treated by static analysis. Figures 9a, b show how stress and deformation of the facade glass panel, in the case of same geometry and thickness of 20 mm as in the previous cases, are minimized due to the linear supports throughout the whole scope of the panel.



a) b)

Figures 9a, b. Normal flexural stress (a) and deformation (b) of the flat glass panel of 20 mm thickness, linearly supported on their edges by vertical and horizontal load-bearing elements of the facade substructures (story height 4 m).

Conclusions

From the standpoint of rationality of the construction, the setting of vertical elements of the facade substructures is crucial, whether they are visible on the facade or invisible – placed behind the glass layer, whether they are metal or glass elements, whereby it implies that panel is attached to the building structure also at the ceiling level. If the vertical substructure element is predicted, there is no significant difference in stresses and deformations of glass panels, whether the vertical substructure element is a direct linear support of the panel or indirectly receives the concentrated force from point support to which the glass panel is directly attached. Avoiding vertical elements of the bearing facade substructures, in case of panel which height is at least twice larger than its width, significantly affects the increase in material consumption and thickness of glass panels.

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