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Mechanical Resistance of Triple Glass Facade Panels

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Abstract Loading tests of triple glazed facade panels with dimensions of 1.5 x 2.64 m were carried out. The purpose of the tests was to examine mechanical resistance of the glass panes, namely the deformations caused by a local load, to determine degree of interaction between the panes of triple glazing exposed to the loading action and to prove the load bearing capacity of the panels. This experimental investigations were accompanied by finite element analysis.

Introduction

One of the tools used for reducing the heat loss in building structures is to apply insulation glass in windows. These glasses have significantly better thermal insulation properties than traditional methods for glazing window openings. In practical applications, double or triple glazing is used. The panes are separated by an insulating spacer, and the space between the panes is filled with an inert gas. The effectiveness of a triple glass window can be expressed as the heat transfer coefficient value U up to 0.3 to 0.2 W/m^{2}K. This glass also reduces condensation on the surface of the pane and icing on the outer face. In addition, it has favorable acoustic insulation properties in urban areas affected by traffic noise. Disadvantages of this type glazing are its greater weight and its higher price.

In the building structure such facade panels can be, depending on the structural system, subjected to mechanical and temperature loads which they must safely sustain. Absence of valid standards for practical design and assessment of the insulating members leaded to the requirement to investigate the mechanical resistance of these construction parts by experimental as well as numerical way [1-5]. Laboratory loading tests have been performed in order to:

- determine response of the panels to the test load - deflections, strains,
- investigate the interaction between glass panes in the triple glazing,
- determine load bearing capacity of the panels by testing to failure.

The test specimens were facade panels with dimensions of 1.5 x 2.64 and triple glazing made of three layers of float glass. Several tests were performed under various loading conditions:

- a single load of 0.75 kN,
- a double load of 2 x 0.75 kN, including the dynamic effect,
- linear loading of 1.5 kN / m ', i.e. a total load of 2.25 kN,

- a single load until the failure.

In total, three samples were tested. The main purpose of the tests was to determine the degree of deformation interaction between the individual glass panes. Only the results of the single load test until failure are presented here.

Experimental investigation

Triple glass panels with dimensions 1500 x 2640 mm were made in the Pilkington company workshop (Noviny, Ralsko). Foil strain gauges were placed on the lower face of the panes (outside facing) before they were bonded. The gauges enabled measurements to be made of the strains in two directions perpendicular to each other: transverse and longitudinal.

The triple glazing consisted of 8 mm Float - 12 mm Ar TGI - 6 mm Float - 12 mm Ar TGI - 66.2 Float. The glass panes were bound by distance spacers, and an inert insulating gas (Ar) was injected into the cavity between the panes. The interior facing consisted of laminated Float glass bonded by PVB foil.

The purpose of the preliminary tests was to measure the deformation of the glass panes, in order to determine the degree of interaction between the panes of insulating triple glazing when exposed to an internal load. The test results were used as a basis for static design of real structures.

During the test, the panel was simply supported along the perimeter by a wooden frame with dimensions 80 x 80 mm. The simple load (100 x 100 mm, steel plate supported by a felt pad) due to the hydraulic operating system was the only burden on the surface of the glass. The data from the experimental investigations was registered by a data-logger.

Experimental results

The loading tests were controlled by constant deformation increase of 0.02 mm/s. Failure of the specimen occurred at the load F_{max} in the second glass pane from the internal side of facade panel in all cases. The results of the experimental investigations are summarized in Table 1; strain diagrams in lateral and longitudinal direction are presented in Figs. 4 and 5.

Tab. 1: Experimentally measured data

Specimen	F_{max}	$e_{tr\,1}$	$e_{tr\,2}$	$e_{tr\,3}$	$e_{lon\,1}$	$e_{lon\,2}$	$e_{lon\,3}$	d_{max1}	d_{max2}
No	[kN]	[mm/m]						[mm]	
V1	5,77	341	579	31	31	36	84	2,2	9,0
V2	4,65	304	511	31	31	36	81	1,8	7,6
V3	6,65	384	665	41	41	48	107	2,7	9,8

F_{max} ... max force,
$\varepsilon_{tr\,1,2,3}$... max transverse strain,
$\varepsilon_{lon\,1,2,3}$ ... max longitudinal strain,
$d_{max\,1,2}$ ... max deflection

Numerical simulation

The experimental investigations were supported by numerical simulation using ATENA FEM software [6,7]. This program allows to model building structures and their parts taking into account real material properties, its response, damage and failure. This enables to follow

Fig. 1 Panel in the testing frame

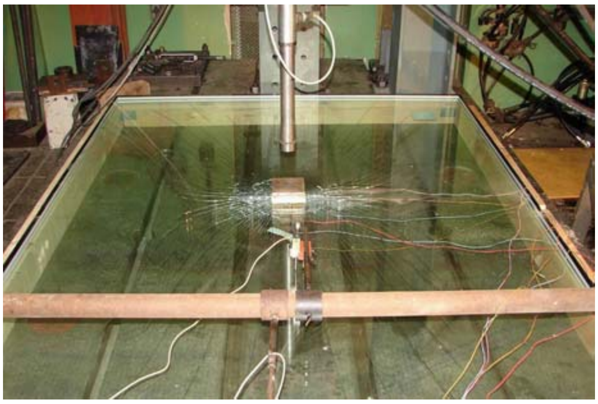

Fig. 2 Panel after failure

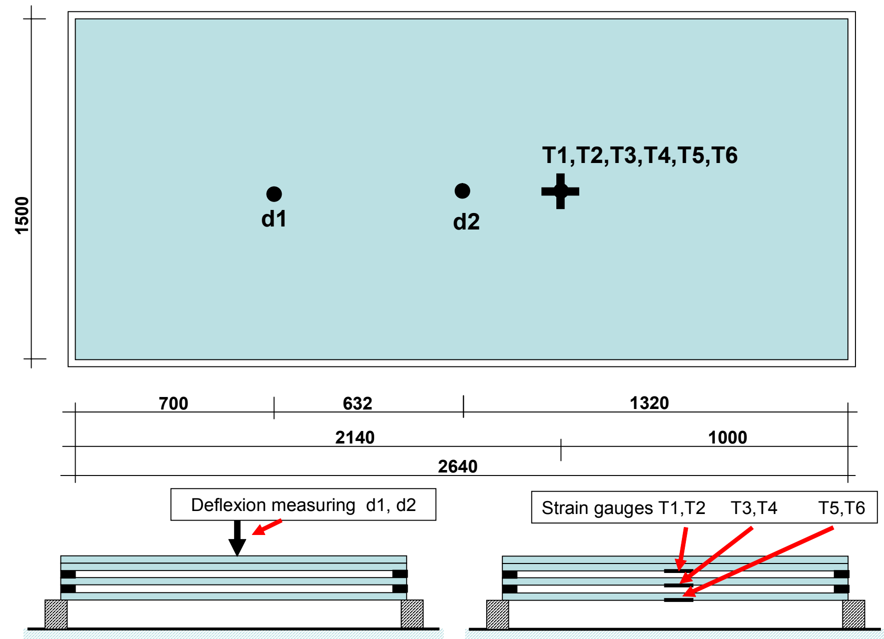

Fig. 3 Scheme of measurement

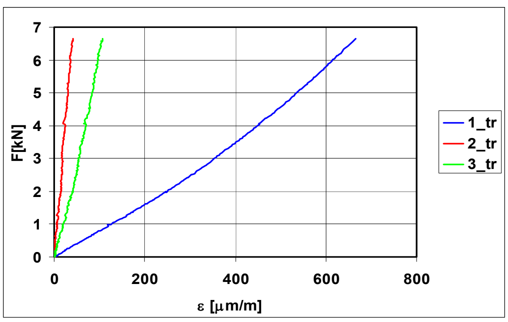

Fig. 4 Diagram of transversal strains

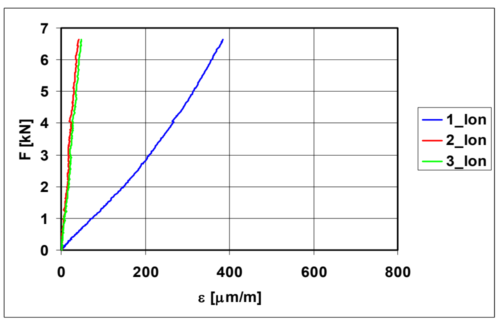

Fig. 5 Diagram of longitudinal strains

structural behavior and response in similar way as during testing the real structure. The elite nonlinear material models employed within the FEM software are based on nonlinear fracture mechanics approach taking into account tensile strength as well as fracture energy of the construction materials. The software was originally developed for simulation of concrete and reinforced concrete structures which exhibit quasi-brittle failure but using appropriate material properties and parameters it is able to simulate also response and cracking of brittle structures like glass panes in rather realistic way. Due to special features included in the software (crack band theory) the numerical analysis is insensitive to the finite element meshing and together with the inner energy based convergence criteria it assures good quality and objectivity of the numerical results. Evaluation of results from the numerical simulation provides better insight into material and structural response during the loading process comparing to the experiments. However, the experiment are necessary to adjust and confirm appropriate material parameters of the nonlinear models and for validation of the FEM model.

In this particular case the numerical analysis of experimental loading tests of triple glazed facade panels has been performed. Model of the tested specimen with the finite element mesh, boundary conditions and loading is shown in Figs. 6 and 7. The model consists from 450 volumetric finite elements; glass panes and the inert gas are modeled by layered quadratic plate elements. The triple glazed panel is, in accordance to the test setup, supported by a timber frame; the loading is realized through distribution plate with the size of 100x100 mm. These side parts are modeled by linear hexahedra volumetric elements with appropriate material properties.

The actual results from the numerical analysis, shown in Figs. 8 to 13 document satisfactorily functionality of the numerical model and exhibit well qualitative agreement between the simulation and experiment. For better quantitative conformity of achieved results further investigations will be needed in order to adjust appropriate material parameters for all parts - glass, inert gas, distance spacer, wood frame - by means of inverse analysis, based on experimental data and test results.

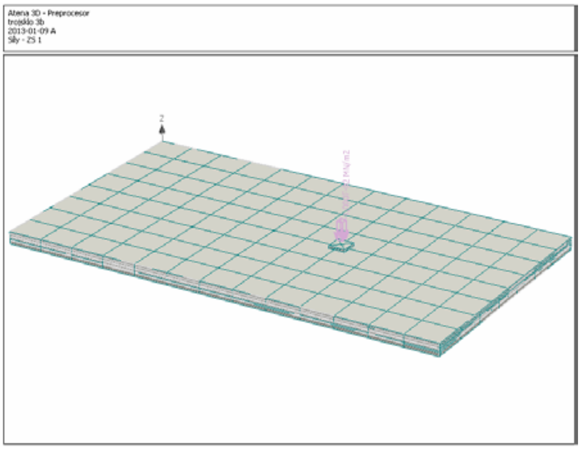

Fig. 6 FE model with the loading scheme

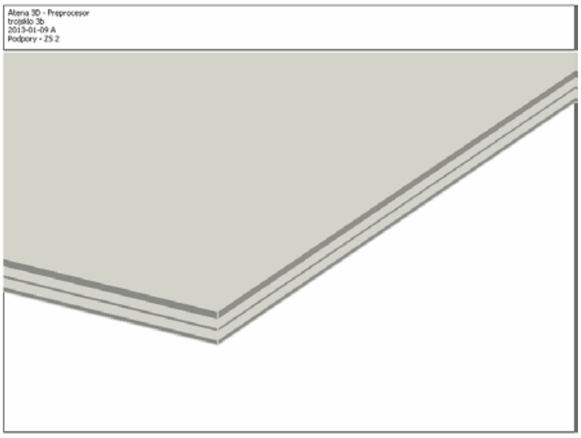

Fig. 7 Detail of the numerical model - glass layers - thickness from the bottom: 8, 6 and 12,8 mm, spaces (Argon gas) of 12 mm each

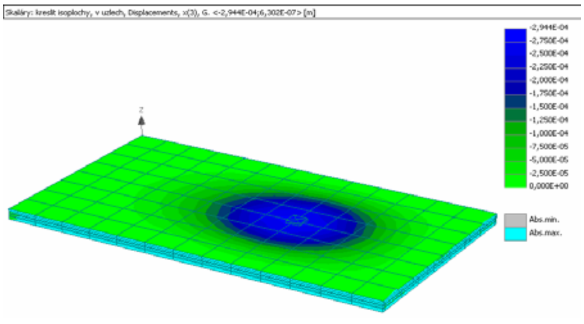

Fig. 8 Calculated vertical deflections

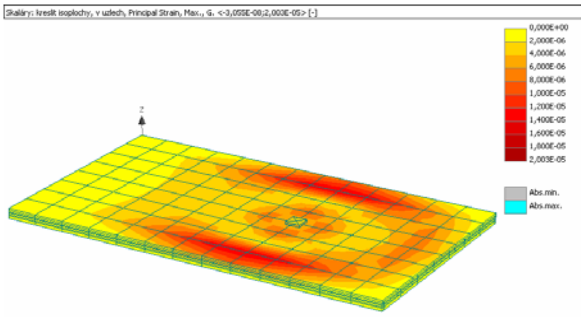

Fig. 9 Calculated strain distribution

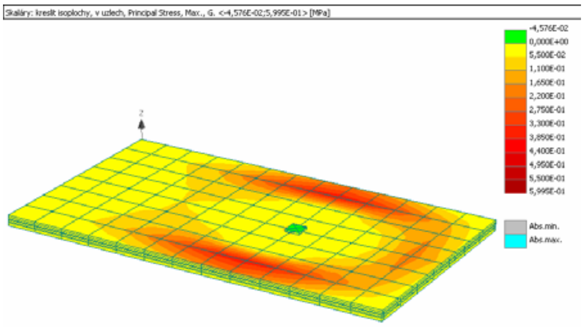

Fig. 10 Calculated tensile stress distribution

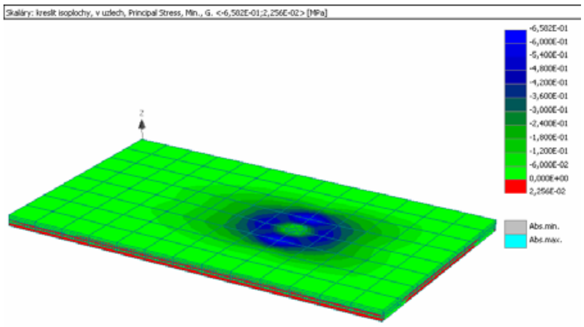

Fig. 11 Calculated compressive stress distribution

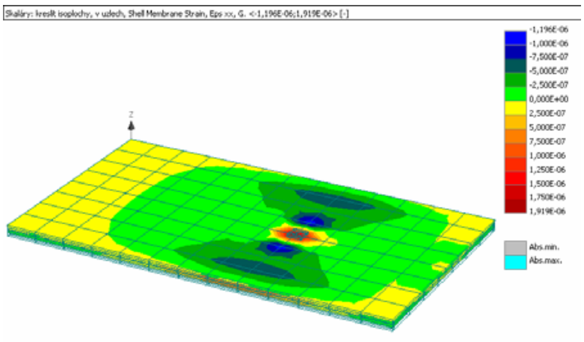

Fig. 12 Membrane deformations on the upper surface, dir. X

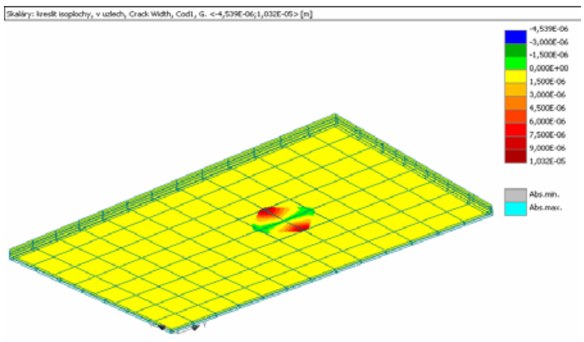

Fig. 13 Onset of cracks in the bottom layer

Summary

The results of experiments carried out on three samples of triple glazing in laboratory at the Klokner Institute showed that:

- the individual panes of glass partly interacted under the action of the load,
- during the test only the inner pane of laminated glass failed (i.e. the second pane from the surface). The glass on the face was undamaged.

Acknowledegment

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