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Lateral and Torsional Stability of Glass Beams

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Abstract: In modern architecture glass has got more and more importance because of its transparency, filigree appearance and lighting functions. For that reason glass belongs nowadays to one of the most progressive materials with new function. It is not only the filling material but also very often material for the load bearing structural elements. Design of structural glass is currently limited by the lack of knowledge and rules, especially in case of stability problems of glass beams or columns. Existing design methods for other materials cannot be directly transferred to glass.

Keywords: Glass Beam; Stability; Experiment; Numerical Model; Initial Imperfection.

1 Introduction

Glass is a material, which is able to resist very high compression stresses and which has special architectural appeal because of its transparency. For this reason, there is a growing trend to extend the use of glass sheets to load carrying elements such as beam, columns and shear panels. Due to their high slenderness, such load carrying elements tend to fail because of instability (e.g. column buckling, plate buckling or lateral torsion buckling) [1–3]. This paper is focused on the last case of instability – lateral torsional buckling. The research was aimed to the experimental investigation of stability problems of single layered and laminated glass and parametric study based on the numerical model which was verified by experimental results.

2 Stability Problems

Existing design methods for other materials cannot be directly applied for stability problems of glass beams. There are several points which have to be taken into account:

- initial deformations,
- production tolerances of glass thickness,
- damage of the glass surface,
- load duration,
- glass strength,
- behaviour of interlayer (PVB foil, EVA, ionoplast).

2.1 Initial Deformation

The initial deformation is different for various kinds of glass. The annealed glass has very low initial deformation. It is smaller than L/2500, where L is the length of the beam. Tempered glass has higher initial deformation up to L/300. This is caused by production of tempered glass which is warmed up 650 °C and then rapidly cooled. During this process the glass panes are placed on rollers, which cause sinusoidal initial deformation.

2.2 Tolerances of Glass Thickness

Thickness of annealed glass is often less than the nominal value which manufacturers declare. Due to the smaller thickness, the second moment of the area is lower and the load carrying capacity of the beam is adversely affected.

2.3 Damage of Glass Surface and Behavior of PVB Foil

Tensile strength of float annealed glass is influenced mainly by the micro- and macro-cracks at the surfaces. Surface damages such as scratches and notches are caused by abrasion, wind and other mechanical effects. Under the loading due to the tensile stresses cracks on the surface growth to the critical length when the glass breaks by brittle failure.

Laminated glass composed of two or several glass panes connected by transparent interlayer is used in case of load bearing structural elements. Composite action of panes under the loading is affected by the material properties of polymeric interlayers (e.g. PVB – polyvinyl-butyral), particularly by the shear modulus which is sensitive to the temperature and load duration. Thus viscoelastic behavior of the polymeric foil influences the behavior of the glass beam under loading.

3 Experiments

Experiments focused on stability problems of glass beams were performed in experimental center of Faculty of Civil Engineering, CTU in Prague. Twelve beams with depth of section 360 mm and thickness 8, 10, 12 mm from single layered float glass and 12 beams with the thicknesses 2 × 8 mm, 2 × 10 mm and 2 × 12 mm from laminated float glass with PVB foil were prepared for testing [4]. The test specimens were 3000 mm long and the supports were situated 650 mm from the ends of the beam. Simply supported beam with overhanging ends was subjected to a concentrated load at the ends of the beam, Fig. 1.

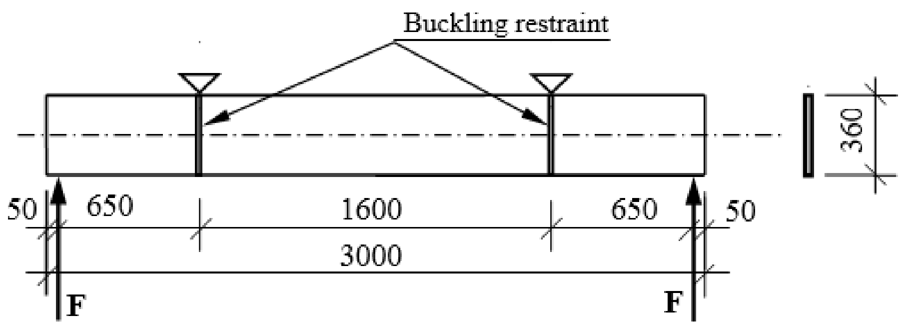

Fig. 1: Schematic test setup of experiments.

The test specimens were loaded by controlling the force value. Application of the load was carried out step by step with time interval 60 seconds. During the tests the stress distribution on the glass surface was measured indirectly by four strain gauges LY11-10/120. The lateral and horizontal displacement and inclination of the section at mid-span were measured too. Test set-up of the experiment is shown in the Fig. 2.

4 Results of Experiments

All test specimens failed suddenly without any warning. Brittle failure started always on the tensile bottom edge of the cross-section in the middle part of the beam, i.e. in the part with maximal bending moment. Typical failure mode is demonstrated in the Fig. 3. Glass fragments after the collapse remained together adhered to the PVB interlayer in case of laminated glass beams.

The measured values for single layered glass beam with thickness 8 mm are summarized in Tab. 1.

Tab. 1: Summarized results of single layered glass beam with thickness 8 mm.

Specimen	Maximum horizontal displacement [mm]	Maximum load [kN]	Maximum tensile stress [MPa]
F08-01	10.9	6.52	24.64
F08-02	39.9	7.66	55.51
F08-03	41.8	7.14	46.48

Fig. 2: Test set-up in laboratory.

Fig. 3: Typical failure mode of test specimens.

5 Numerical Model

The software package ANSYS 11 was used for the numerical analysis of tested glass beam subjected to bending. Due to the symmetry of the test specimen, only one half of the beam was modeled and symmetry conditions were employed, Fig. 4. Numerical model of the beam was created using an element SOLID45. Material model of the glass was linear isotropic with modulus of elasticity E = 70 GPa and Poisson number 0.23.

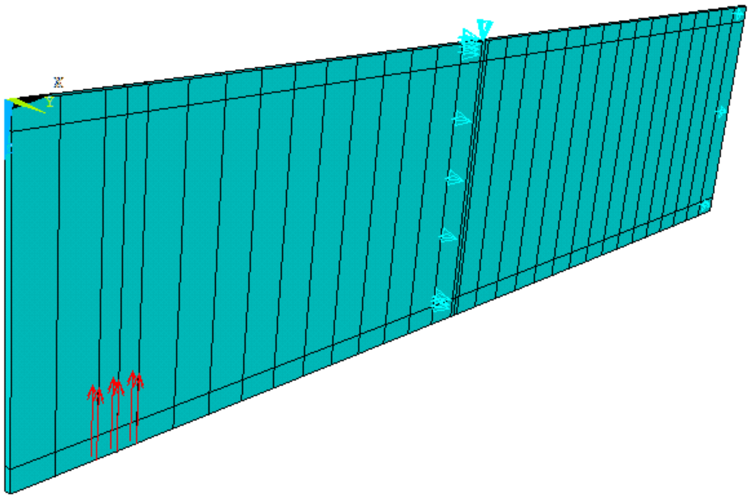

Fig. 4: Numerical model.

Significant influence on the lateral and torsional stability of the glass beams has an initial imperfection which depends on type of glass and manufacturing process. This imperfection was taken into account to obtain the agreement between the numerical model and experimental results. Geometrical imperfection was implemented to the model in a sinusoidal waveform of the beam with different amplitudes, Fig. 5.

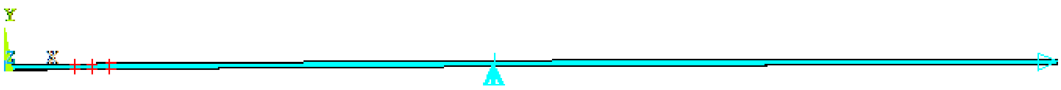

Fig. 5: Numerical model, Z axis view.

The comparison of FE calculation with experimental results is shown in Fig. 6 for the test specimens of glass beam with the web thickness 8 mm. Numerical model without imperfection and with the amplitude of geometrical imperfection L/400, resp. L/1000 was analyzed by this FEM. Numerical model with the amplitude of geometrical imperfection L/400 corresponds to specimen F8-01 and F8-03. Fig. 6 also illustrates that the test specimen F8-02 had lower initial deformation than F8-01 and F8-01. The experimental results for F8-02 specimen are closed to the results of the numerical model without geometrical imperfection.

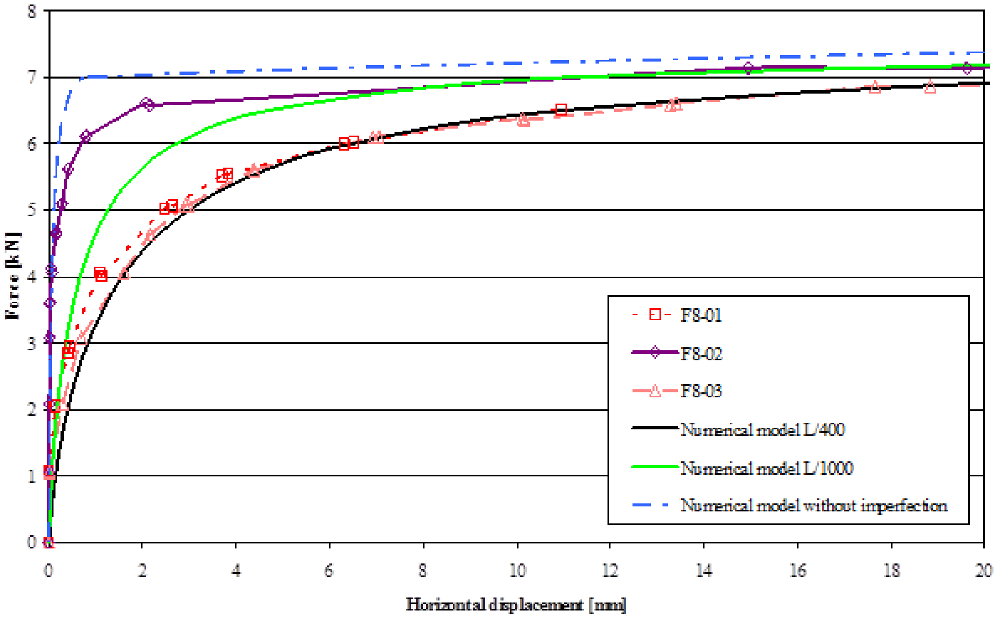

Fig. 6: Comparison of the experiments and numerical analysis.

6 Conclusion

Lateral and torsional stability of glass beams were investigated by set of experiments for rectangular cross-section. Numerical model of the beam was verified by the experimental results. Significant influence of initial imperfection to the buckling of the beam was demonstrated by the numerical model without imperfection and with geometrical imperfection L/400, resp. L/1000.

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