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Experimental and analytical assessment of lateral torsional buckling of laminated glass beams

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ABSTRACT

Due to their increasing use in contemporary architecture, the lateral torsional buckling performance of laminated structural glass beams represents a topic of great interest for researchers. Although several analytical models and design approaches have been recently proposed, various aspects complicate the realistic prediction of this phenomenon. Based on experimental results of a large campaign of lateral torsional buckling tests (55 laminated beams), the paper investigates analytically the effects of various mechanical (e.g. the stiffness of interlayer) and geometrical properties (e.g. initial twist, production tolerances) on the typical lateral torsional buckling response of laminated glass beams.

1. Introduction

Stability issues are known to be of major importance for the proper design of loadbearing glass components and structures [1–9]. As far as stability of glass beams is concerned, several authors have already addressed lateral torsional buckling (LTB) and have proposed design approaches [2–4]. However, in spite of the latter, to date the influence of several parameters on the buckling resistance of glass beams has not always been fully understood. Regarding initial geometrical imperfections for instance, extensive experimental data is available about initial curvature [10], also known as global bow, but initial rotations of the beam's cross-section along its longitudinal axis, also known as twist, are usually not considered. Consequently, based on new data of 55 full-scale lateral torsional buckling experiments on laminated glass beams in combination with numerical modelling techniques, this contribution focuses on the importance of initial twist on the buckling behaviour of laminated glass beams. Particular attention is also dedicated to the effects of possible production tolerances in glass thicknesses. As shown by means of several experimental and analytical comparisons, initial twist and real glass thicknesses can strongly influence the structural behaviour of laminated glass beams in buckling.

2. Materials and methods

2.1. Test specimens

Throughout the experimental campaign, a total of 55 laminated glass test specimens with two glass layers each had been tested, subdivided in 12 series. Differences between series are related to differences in interlayer materials (polyvinyl butyral (PVB) and SentryGlas$^{(R)}$ (SG)), glass type (annealed (AN), heat-strengthened (HS) and fully tempered (FT)), and geometrical parameters (thickness t, height h and ratio between total length L and height h). All test specimens were characterized by a total length L = 3000 mm. Nevertheless, due to beam restraints, the effective buckling length considered in calculations was L_0 = 2900 mm. An overview of specimens is presented in Table 1.

2.2. Experimental methods

All experiments have been performed in laboratory conditions. Temperature registrations during the tests varied between 18.5 °C

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Table 1
Overview of LG test specimens used during the experimental campaign. All specimens had polished edges. Glass types AN, HS and FT represent annealed, heat-strengthened and tempered glass, respectively.

Series	Glass type	Interlayer material[a]	Length L (mm)[b]	Height h (mm)	Length/height L/h (–)	Glass thickness t (mm)	Number of specimens	Origin
B	AN	PVB	3000	120	25	2 × 6	4	EU
A		PVB	3000	120	25	2 × 8	4	EU
C		PVB	3000	150	20	2 × 6	4	EU
D		PVB	3000	150	20	2 × 8	4	EU
F		PVB	3000	300	10	2 × 10	5	Asia
S	HS	PVB	3000	300	10	2 × 10	5	Asia
E	FT	PVB	3000	200	15	2 × 6	8	EU
T		PVB	3000	300	10	2 × 10	5	Asia
G		SG	3000	200	15	2 × 6	4	EU
I		SG	3000	200	15	2 × 8	4	EU
H		SG	3000	300	10	2 × 6	4	EU
J		SG	3000	300	10	2 × 8	4	EU
							55	

[a] Interlayer thickness was 1.52 mm for PVB and 2.28 mm for SG.
[b] Due to beam restraints, the design buckling length assumed in all the calculations proposed in this work is L_0 = 2900 mm.

and 20.5 °C. Consequently, with good approximation a constant operating temperature of 19.5 °C will further be assumed for the analytical predictions of all tests.

2.2.1. Initial shape imperfection measurements

Initial shape imperfections in general, and global bow in particular, are generally known to be of importance in many instability problems, including lateral torsional buckling. Consequently, prior to the actual buckling tests all test specimens were thoroughly measured to obtain accurate values of the global bow, both in terms of shape and amplitude. A custom-made measurement setup was used, in which a linear variable differential transducer (LVDT) was moved at constant speed along the full length of the specimens while registering the relative distance to a reference rail at each measurement location. Obviously, initial shape imperfections of the reference rail itself were filtered out not to influence the results. A detailed description of the full measurement method and equipment has been reported on earlier and will therefore not be repeated here [10].

2.2.2. Lateral torsional buckling test setup

The lateral torsional buckling test setup is illustrated in Fig. 1 and consisted of a large steel frame basis on which (1) custom-made supports, (2) load system and (3) data-acquisition can be mounted according to the test specimen geometry. These three components are subsequently discussed below in more detail. As depicted in Figs. 1 and 2, an orthogonal coordinate system is used in which the directions of X, Y and Z-axes correspond to the horizontal direction perpendicular to the test specimen, the vertical direction, and the longitudinal direction of the test specimen, respectively.

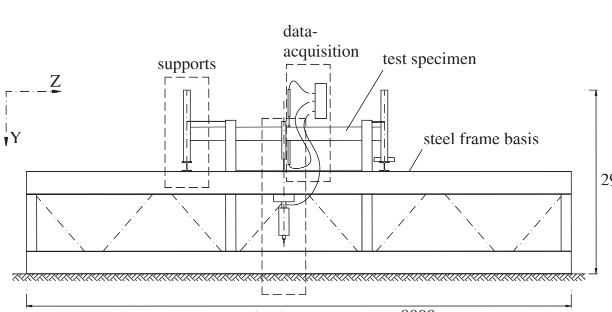

Fig. 1. General overview of lateral torsional buckling test setup. All dimensions are in mm.

Firstly, the supports are designed as fork bearings which restrain rotations about the longitudinal axis (i.e. Z-axis) but enable rotations about the other axes (X- and Y-axis). However, to be in line with common theoretical assumptions, it is essential to avoid friction during rotations. Consequently, high-quality bearings and low friction mylar interlayers were used to minimize friction during rotations about the Y- and X-axis, respectively (see Fig. 2). According to good practice, 2 mm rubber or aluminium contact strips were additionally used at the load introduction points to avoid high local stress concentrations in the glass.

Secondly, loads were indirectly introduced at mid-span by a hydraulic jack, pulling downwards a cross-beam, which was positioned on top of the test specimen. However, to be in good agreement with analytical solutions, which usually assume a gravity load, it is essential that the load remains vertical during the test. This is a challenge for the test setup, because the load introduction point at mid-span will rotate and laterally displace due to torsion and out of plane bending of a test specimen subjected to LTB. To enable rotations at the load introduction point, loads were introduced on the upper edge of the beam by means of a sharp wedge, which could freely rotate about the longitudinal axis in a gutter (see Fig. 3). To enable lateral displacements, the hydraulic jack was mounted on a rolling device so that it could move in lateral direction to follow the out-of-plane movement of the load introduction point as the test specimen was bending out of plane during the buckling test. The test procedure was displacement controlled.

Finally, data acquired from the tests consisted of the applied load, measured by a load cell, and lateral and vertical displacements of the upper edge of the test specimens near mid-span, measured by LVDTs, each obtained at a rate of one measurement per second.

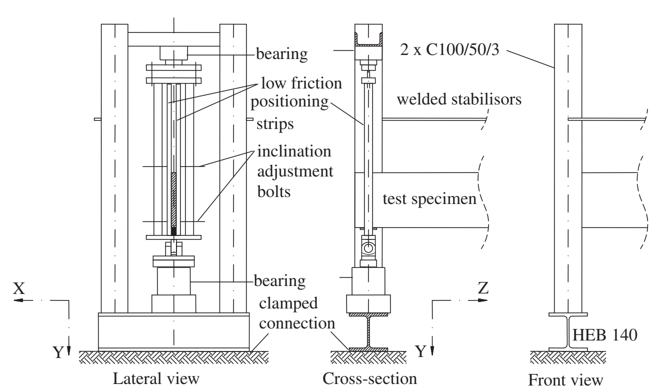

Fig. 2. Details of supports, which enable free rotations about X-axis and Y-axis.