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Coupled experimental and numerical investigation of structural glass panels with small slenderness subjected to locally introduced axial compression

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ABSTRACT

Primary load-bearing glass constructions are often subjected to relatively important in-plane loads, transferred through so-called point-fixed connections. The according in-plane load introduction, structural resistance and failure mechanisms have been studied abundantly for axial tensile loading cases, but are relatively unknown for axial compression, in particular when buckling of the compressed component cannot occur. Consequently, stress distributions, resistance and failure mechanisms of small glass specimens subjected to locally introduced axial compression are investigated and presented in this contribution using a coupled experimental and numerical approach. The stress distributions and observed fracture patterns demonstrated that the major failure mechanism was splitting tension: the glass fractured due to high tensile stresses following the compressive stresses. However, the maximal principal tensile stresses at the crack origin were significantly lower compared to the axial tensile loading case. In addition, and in contradiction to the tensile loading case, significant maximal principal compressive stresses were found at the crack origin, leading to the conclusion that the axially compressed glass panels failed due to a complex stress state and not simply to tensile stresses, as is generally assumed in glass design.

1. Introduction

Load-bearing glass components are becoming relatively well-accepted in contemporary building design and construction. Being part of the primary or secondary load-bearing building structure, such components can be subjected to significant and various loading types. Apart from loads perpendicular to the glass surface, such as wind, structural glass components (and their connections) will often be subjected to major in-plane loads, including axial tensile and compressive loads. Some typical examples of glass constructions subjected to major in-plane loads are illustrated in Fig. 1.

To transfer loads between structural glass components, it is relatively common to use so-called point-fixed connection devices, which usually require small metal components to be mechanically attached to boreholes in the glass (friction-grip connections are not meant here). From a mechanical analysis point of view, this problem can often be considered as a contact problem of two cylindrical bodies, which has been described by several authors [1–4].

However, when applied to glass structures, the knowledge about the mechanical behaviour of in-plane loaded components varies dramatically depending on whether tensile or compressive loads are considered.

The in-plane tensile loading case has been studied extensively in literature, e.g. in [5–8], and stress distributions, failure loads and crack patterns are relatively well known.

However, reports on point-fixed glass components subjected to axial compression are very limited, not to say nonexistent. The main reason for this is that the mechanical behaviour of compressed glass components is usually governed by stability issues: over the past few years, several authors have demonstrated that buckling problems (flexural buckling, torsional buckling, lateral torsional buckling, plate buckling and shear buckling) are of utmost importance to define the overall load-bearing capacity of structural glass components in general [9–12] and of glass compression members in particular [13–18]. However, additional (and currently missing) knowledge of the load-bearing capacity of structural glass compression members in which no stability problems can occur would be relevant, e.g. in case of glass components with a very limited buckling length or adequate out-of-plane supports.

Consequently, this paper presents a coupled experimental and numerical investigation of small-scaled axially compressed monolithic and laminated glass components in which loads are locally introduced by means of a point-fixed connection device.

2. Experimental investigation

Below, an experimental investigation is presented of glass panels subjected to locally introduced axial compressive loads. In

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Table 1
Main test results for specimens subjected to locally introduced in-plane loads.

Specimen name	First compressive breakage load $F_{c,b}$ (kN)	Ultimate compressive failure load $F_{c,u}$ (kN)	Elongation at failure $\delta_{c,u}$ (compression case) (mm)	First tensile breakage load $F_{t,b}$ (kN)	Ultimate tensile failure load $F_{t,u}$ (kN)
1 × 6-1	19.12	17.64	6.97	12.00	14.25
1 × 6-2	16.32	18.92	5.70	13.26	15.08
1 × 6-3	15.80	19.48	7.55	14.60	21.56
2 × 6-1	33.68	23.20	3.74	24.56	17.96
2 × 6-2	30.44	28.76	2.55	20.04	18.72
2 × 6-3	23.52	21.24	3.43	32.60	32.60
2 × 8-1	48.88	41.24	2.44	38.92	38.92
2 × 8-2	46.04	36.88	3.61	39.48	39.48
2 × 8-3	51.12	35.28	4.35	49.80	49.80

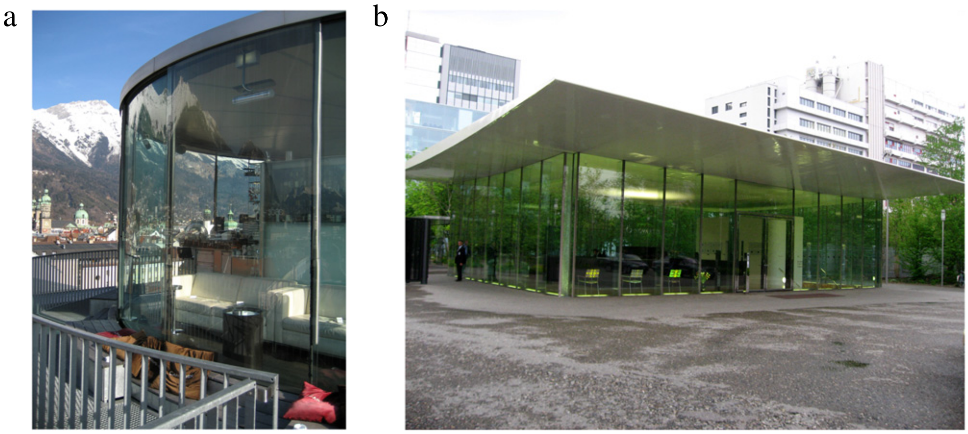

Fig. 1. Examples of in-plane loaded structural glass constructions: (a) Innsbruck: Load-bearing curved glass walls café Lichtblick (Dominique Perrault, 2005); (b) Basel: (shear) walls at the Novartis campus entrance building (Marco Serra/Ernst Basler & Partner AG, 2006).

addition, uniaxial tensile tests have been executed on identical test specimens to allow a comparison of both loading cases.

2.1. Specimens

For both loading cases, nine heat-strengthened glass specimens of 200 mm by 500 mm have been tested, further divided in three series of three specimens with a different glass thicknesses and/or composition:

6 mm monolithic glass (1 × 6);
6 mm glass/1.52 mm PVB/6 mm glass laminates (2 × 6) and
8 mm glass/1.52 mm PVB/8 mm glass laminates (2 × 8).

The specimen edges and boreholes were polished and chamfered. The slenderness of the test specimens was chosen such that stability problems could not occur. More specifically, to avoid buckling, the specimen length was limited. As the other dimensions, such as the glass thickness, the borehole diameter, etc. had not been rescaled, no significant scale effect was further considered.

Every specimen had been provided with two boreholes (Ø 42 mm) in which axially rigid bolted connection devices had been placed to introduce the loads [18]. These connection devices consisted of a steel M20 bolt, a steel tube and a steel cylinder, as illustrated in Fig. 2(c). Between the steel cylinders and the glass a liner material (POM) was placed to avoid direct contact between glass and steel. Subsequently, after the assemblage of the connection devices, Hilti HIT HY 50 mortar [19] was injected in the glass boreholes, filling up the free intermediate space caused by the tolerances of the steel tube and the glass drillings. In doing so, the loads could be introduced to both sheets of the laminated glass specimens in a uniform way, avoiding high local stress concentrations in the glass.

2.2. Method

The specimens were subjected to an axial compressive load (F_c) through the load introduction system depicted in Fig. 2. During the displacement controlled tests, the deformations of the glass plates as well as the stress distributions around the borehole and at mid span were measured by linear variable differential transducers (LVDT) and strain gauges respectively.

2.3. Results and discussion

The main test results are presented in Table 1, which tables the first breakage load ($F_{c,b}$), the failure load ($F_{c,u}$) and the corresponding elongation at failure ($\delta_{c,u}$) of the specimens subjected to compressive loads. To allow a comparison, the first breakage load ($F_{t,b}$) and the ultimate failure load ($F_{t,u}$) for the tensile case are tabled as well. In addition, Fig. 3 depicts the relation between the specimens' longitudinal displacements (δ_c) and the applied in-plane compressive load (F_c).

2.3.1. Failure mechanisms

The three test series demonstrated different failure mechanisms.

In the (1 × 6) specimens, crushing of the mortar due to high compressive loads occurred before breakage of the glass plates. This crushed mortar lead to cracking of the glass due to contrapressure of the steel tube and the glass. However, based on the a posteriori inspection of the tested samples (see Section 2.3.3), it is unlikely that direct contact between glass and steel components took place. Consequently, the specimens demonstrated relatively large, nonlinear displacements and the ultimate glass plate failure did not take place suddenly (Fig. 3(a)). Instead, a progressive failure was observed: after crushing of the mortar and the first breakage