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Experimental and Numerical Investigation of the Buckling Performance of Tubular Glass Columns under Compression

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ABSTRACT

This study investigates the buckling performance of tubular glass columns under axial compression. A total of two cases are considered (i) single glass tubular column and (ii) bundled column constructed using structural silicone sealants. A series of compression test were carried out on different geometrical dimensions of these two cases to determine their failure mechanism, load carrying capacity and to evaluate the buckling performance. Prior to the load carrying capacity (LCC) that was measured at the ultimate, a distinctive remaining structural capacity (RSC) was characterized especially for bundled glass based on the first crack. The shear connection in the bundled system was justified in comparison to the monolithic glass. This study showed that the failure mechanisms depended strongly on the slenderness ratio of the columns and that the failure occurred either by crushing or by buckling depending on the lengths of the column. The scatter in the failure load for specimens that had a higher slenderness ratio was much lower than for those that had a lower slenderness ratio. In order to justify the variability of the glass strength, a Weibull statistical distribution was used. Finite element modelling (FE) based on the simplified Riks method was performed using ABAQUS v6.10 to compliment the test results and to provide methods of analysis which could be used as a guideline for structural engineers to predict structural behaviour of tubular glass columns in general. An overestimation was predicted in the FE models which suggested modification of the imperfection factor.

1. Introduction

The dramatic increase in the use of glass in buildings has shown a significant requirement for glass to be used in a structurally efficient manner [1–3]. Structural element made of glass creates an interesting visual feature because of its uniqueness i.e. its transparent characteristics. However, the brittleness of glass may make it unsuitable, if used for a load bearing structural member. A significant understanding of how glass responds to loads is vital for structural engineers. At present, there is a large amount of published research concerned with the performance of glass structures [5–9] which indicates that in the correct environment structural glass shows good stability and build-ability.

In the early years of glass research [4], the focus was primarily on understanding the material properties of the several types of glass, namely annealed, heat-strengthened and fully toughened glass. An innovation to increase the effectiveness and durability of structural glass was introduced, namely laminated glass. Laminated glass is a form of two or more layers of glass, bonded using an interlayer, created from the combination of those types of glass mentioned above. In general, two types of glass are produced; either float glass which is suitable for the construction industry, or borosilicate glass which is usually used for laboratory glassware. With safety issue being an important factor for structural glass, the maximum benefit of using glass must be obtained ensuring the avoidance of hazards to the public. Thus, laminated glass is prospectively preferable since it has shown reliable performance in buildings [3]. Laminated cruciform glass columns of varying dimensions have been studied [5]. This type of cross-section shape eases the complexity of the beam-column connection. However, the inherent low torsional rigidity of cruciform columns is a disadvantage for structural glass applications when the elements are used in load-bearing structures.

A preliminary study on the buckling strength of glass elements has shown sensible results for a design method for glass members under compressive load [10]. Validation of Euler's buckling calculation for composite rectangular cross-sectional geometrical dimension has shown a reliable application to monolithic or laminated glass columns.

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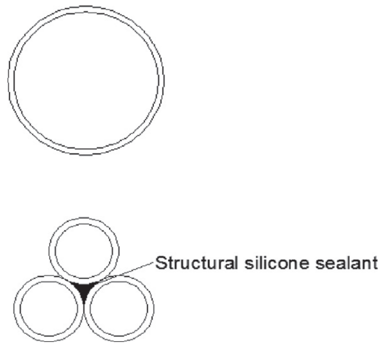

(a) SGC - single-piece hollow section of tubular glass column with a standard length of 1500 mm to the manufacturer specification

(b) BGC - combination of three single-piece hollow section of tubular glass column with a standard length of 1500 mm, bundled together using structural silicon sealants

Fig. 1. The geometrical arrangements of (a) single glass columns (SGC) and (b) bundled-glass columns (BGC).

Table 1
Material properties of structural silicone sealant.

Characteristics	Symbol	Unit	Value
Density	ρ	kg/m^3	1542
Young's modulus	E	MPa	1.72
Poisson's ratio	ν	–	~0.50
Hardness[a]	–	–	60 Shore A
Tensile strength	ft	MPa	2.65
Elongation at rupture[b]	εt	%	> 350

[a] According to DIN 53505.
[b] According to DIN 53504.

Table 2
Details of specimens for SGC and BGC.

Type	Specimen	Length, L (mm)	Outer diameter, d_o (mm)	Wall thickness, t (mm)
T1-S	1–4	1500	60	7.0
T2-S	5–9	1500	60	2.2
T3-S	10–14	1500	50	1.8
T4-S	15–19	1500	24	2.5
T5-S	20–24	1500	20	1.8
T6-B	25–29	1500	20 (per tube)	1.8 (per tube)
T7-B	30–34	1500	24 (per tube)	2.5 (per tube)

d = outer diameter, t = wall thickness, T1, T2.. = type, S = single, B = bundled.

A standard for glass buckling strength curves derived using the elastic, second order equations has been validated by buckling experiments and FE simulation. In [11–14], extensive verification works of composite rectangular cross-sectional glass column have been presented. A

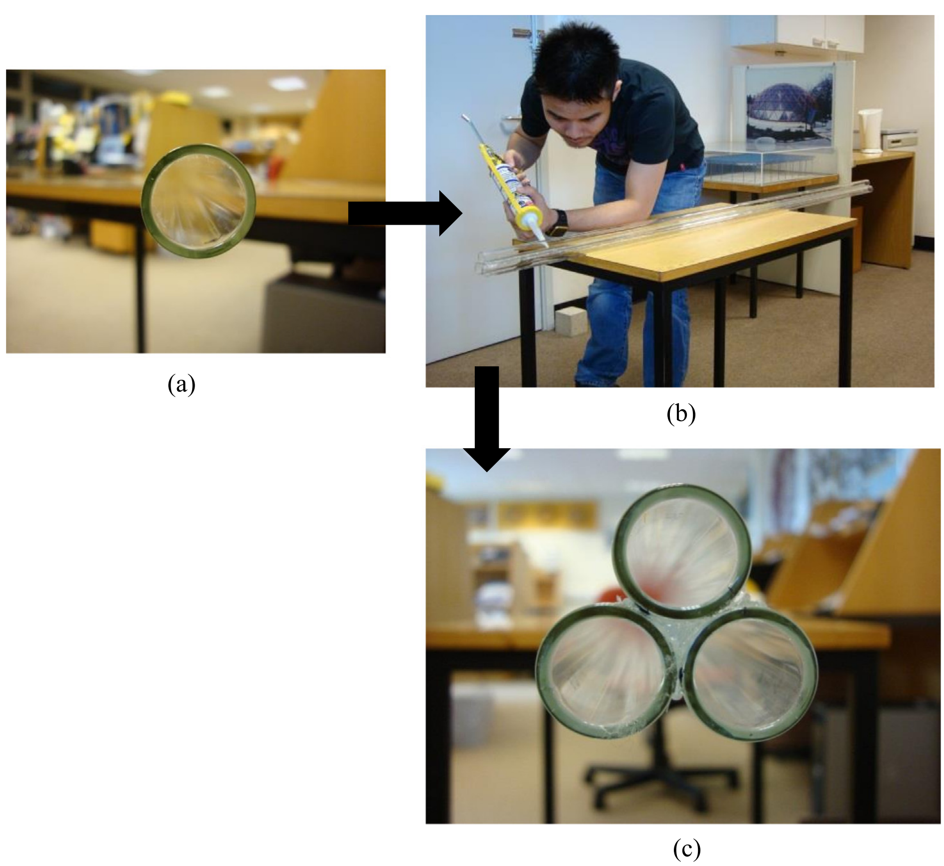

Fig. 2. BGC bonding process by using structural silicone sealant; (a) SGC tube; (b) applying structural silicone sealant; (c) BGC specimen after curing for 24 h.

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