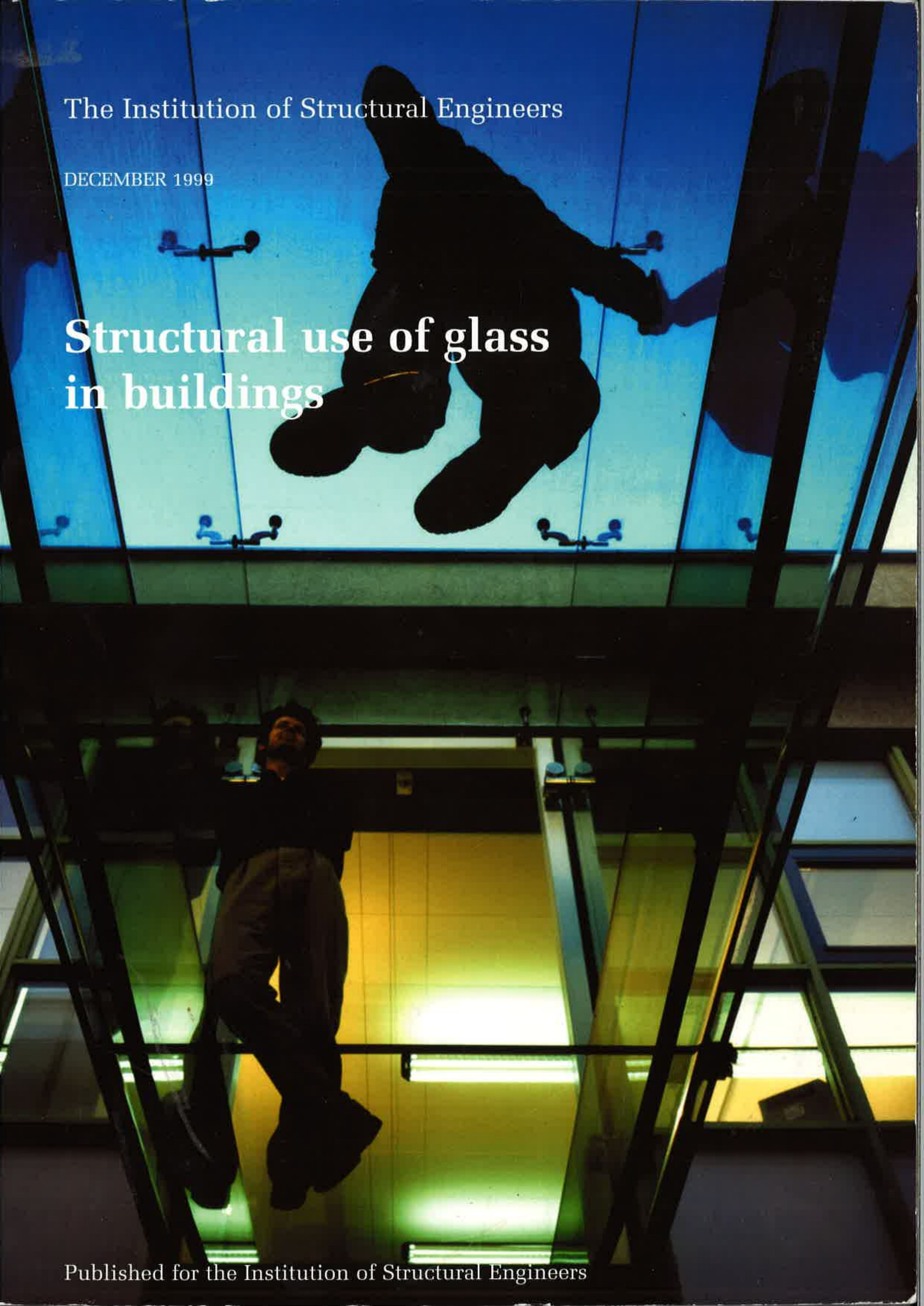

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Structural use of glass in buildings

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Fig. 4.13 Conservatory at a house in Clapham, South London (courtesy Bere Associates/Michael Heyward)

Fig. 4.14 Entrance canopy to KP Foods at Billingham (courtesy of Jeremy Cockayne/Studio BAAD)

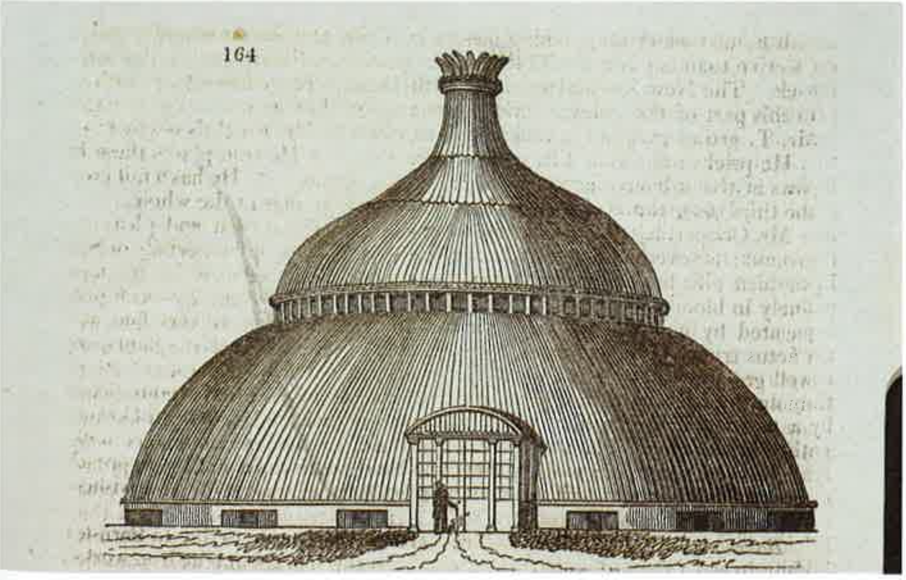

Fig. 4.15 Mrs Beaumont's Dome (courtesy of Royal Horticultural Society, Lindley Library)

glass and because it is at the top of the enclosed space, roof glass may reach higher temperatures than facade glass. The thermal stresses may well constrain the designer to choose toughened glass.

We are all familiar with images of the Palm House at Kew (1848; Architect Decimus Burton; Engineer: Richard Turner), the Crystal Palace in London (1851; Architect and Engineer Joseph Paxton) and with the great Victorian Railway stations. All used or use glass extensively in their roofs, supported by frames of steel or iron. These were preceded by some bulging curved glass houses designed by J. C. Loudon and built by W. & D. Bailey in the second quarter of the 19th century. The delicate wrought iron frames were braced in-plane by the glass. It is reported that the frame of Mrs Beaumont's dome, built in 1827 at Bretton in Yorkshire, swayed alarmingly in the wind during construction but once glazed was steady as a rock.

In all of these wonderful buildings, small panes of glass are supported on two or four edges by frames to which they are attached by putty. This is still a valid way to support glass roofs (but not double-glazed units), even if nowadays we use more elaborate arrangements of structure, glass and sealant.

An obvious successor to the great 19th century glass roofs is the Waterloo International Terminal, with its sinuous roof glazed like the scales on a lizard's back.

Grid shells have long held a fascination for engineers, probably because of their economical use of material but they can be susceptible to unbalanced loads, such as wind-driven snow. The History of Hamburg Museum (1989; Architect: von Gerkan, Marg + Partner; Engineer: Schlaich, Bergermann and Partner) has a modern glass roof that covers a large L-shaped courtyard of a 1923 building. The form of the structure is a pair of intersecting barrel vaults, one about 14m wide and one about 18m wide.

The structure consists of a grillage of 60mm-wide by 40mm-deep solid galvanised steel glazing bars bolted together to form a loadbearing grid of quadrilaterals approximately 1.7m on each side. In-plane stiffness is provided by pairs of 6mm diameter diagonal steel cables. The glass could have provided this itself but Schlaich preferred to make evident the elements that provide the in-plane stiffness and hence chose to use steel cables rather than the glass. Engineers may be confident that the glass can provide all the in-plane stiffness needed but if they want to do so they will need to persuade the checking authorities and the insurers. At three locations fan bracing provides additional out-of-plane stiffness to the vaults.

The size of each glass pane was calculated and cut by computer. The panes are laminated using 6mm sheets of annealed glass. Each pane sits on a strip of neoprene silicone rubber on top of the frame and is restrained at the corners by a wide circular plate at the intersection of the glazing bars. The plate is large enough to restrain the corners of four adjoining panels of glass, using a simple bolt fixing.

The relatively small panel size and the bedding of the neoprene gave a tolerance to accommodate the double curvature of the roof. In places where the curvature was most marked, some glass panels were folded across a diagonal by cutting the upper and lower glass sheets on site and allowing the interlayer to support the fold, protected by site-applied silicone.

Heating cables are provided, not to prevent condensation, but to prevent excessive snow build-up.

8 Glass columns and walls

8.1 General description

Glass columns and loadbearing walls are quite rare. Engineers have generally been reluctant to design compression members in a material that works best in compression!

The reluctance has been based on the brittleness of glass, the fact that it can fail suddenly and without warning. This means that a structure needs to be able to cope with the loss of a column or wall without disproportionate collapse (just like any other structure) and/or the column/wall needs to be well protected against accidental damage.

Recent examples of glass columns and walls include:

Fig. 8.1 Broadfield House Glass Museum (courtesy of Dewhurst McFarlane & Partners/Design Antenna Ltd

Fig. 8.2 Conservatory at a house in Clapham, South London courtesy Bere Associates/Michael Heyward)

- the glass fins supporting the roof of Broadfield House Glass Museum (1994; Architect: Design Antenna; Engineer: Dewhurst McFarlane)
- the stacked glass insulators supporting the roof of a south London conservatory (1995; Architect: Bere Associates; Engineer: Campion & Partners)
- the competition-winning entry for the Construction Tower at the National Exhibition Centre (1998; Architect: Sutherland Hussey Architects with Blyth & Blyth; Engineer: Dewhurst McFarlane)
- the loadbearing glass walls of the Rodin Pavilion at the Samsung Centre, Seoul, South Korea (1998; Architect: Kohn Pedersen Fox Associates; Engineer: Ove Arup & Partners)
- glass rods as the web compression members in trusses by Dutch engineer abt
- glass tubes as compression elements in a tensegrity structure at the University of Stuttgart (1996; Architect: Stefan Gose; Engineer: Patrick Teuffel)
- The 13.5m high, ground-based glass wall at the Royal Opera House, Covent Garden, London (Dodd, 1999)

One design idea for Coventry Cathedral (Architect: Basil Spence; Engineer: Ove Arup & Partners) was to support the main columns on solid glass spheres. This idea was not carried through into construction. Another unexecuted idea, this time for the New Parliamentary Building in London (Architect: Michael Hopkins; Engineer: Ove Arup & Partners), was to support a staircase on a slender steel rod located within, and braced by, a glass tube.

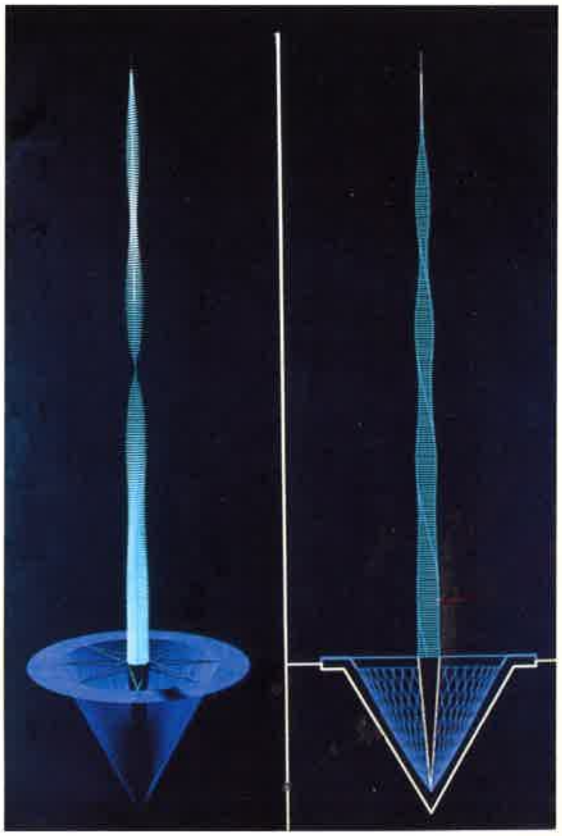

Fig. 8.3 The Construction Tower at the National Exhibition Centre (courtesy of Dewhurst MacFarlane & Partners/Sutherland Hussey)

10 Externally-prestressed glass

10.1 General description

Externally prestressed glass is glass that is compressed by an external arrangement of stressing rods or cables, rather than by toughening or heat strengthening. 'External' means a material other than glass, because the compression could be applied by a steel rod inside, for example, a glass cylinder.

Externally prestressed glass is extremely rare. As with glass columns, engineers have generally been reluctant to design compression members in a material that works best in compression! The reluctance has been based on the brittleness of glass, the fact that it can fail suddenly and without warning.

Externally applied precompression is also comparatively rare in engineering structures, though an example of externally precompressed steel may be found in the roof structure of the passenger terminal at Stansted Airport (1991; Architect: Foster Associates; Engineer: Ove Arup & Partners).

A notable recent example of externally prestressed glass is the competition-winning entry for the Construction Tower at the National Exhibition Centre (1998; Architect: Sutherland Hussey Architects with Blyth & Blyth; Engineer: Dewhurst McFarlane). To be literal about it, even this glass is internally prestressed in that the Kevlar cable that applies the precompression runs through the centre of the glass (Whitelaw and Parker, 1997). However it counts as externally prestressed because it is the Kevlar cable that compresses the stacked glass disks and not heat treatment.

A similar example is the glass column consisting of stacked glass insulators, designed by Bere Associates for a south London conservatory (Welsh, 1995). Threaded through the units to tie them together is a high tensile steel rod.

At Schloss Juval in the South Tyrol (Anonymous, 1997), steel trusses spanning up to 13.4m support a glass roof over a courtyard of an ancient building. The glass spans the 4m between the steel trusses by acting as the compression boom of a simple truss, with a steel cable taking the tension. It is thus, effectively, prestressed by its self-weight (see Figs. 4.22 and 10.2).

Fig. 10.1 Glass column at South London conservatory (courtesy of Bere Associates/Photo: Michael Heyward)

10.2 Rules of thumb

10.2.1 Elastic stability

Chapter 8 on glass columns and walls described three basic stability conditions for compression members and gave the elastic critical load factor, λ_c, for each of these conditions. Guidance on elastic stability can be found in Timoshenko and Gere (1970), Roark & Young (1977) and in appendix A5 of Ashby (1997).

The way that the precompression is applied can significantly affect the buckling length of the member concerned. The external precompression may not be applied symmetrically, for example in the case of a glass beam. Here the analogy is with a prestressed concrete beam. As with prestressed concrete, it is important to remember that precompression is always accompanied by axial shortening. Appendix E addresses the stability of narrow beams.

A non-linear analysis may be necessary for some types of prestressed structure. Although the structure itself does not deform grossly, any small deflection may have an important impact on the overall behaviour.

For example, a small change in geometry may reduce the tensile force in a cable. Unlike prestressed concrete, cables used to prestress glass are usually attached to slender structures so that the change of main structure geometry may affect the cable force significantly. The worked example in section 10.6 is just such a structure.

When the external prestress is applied internally, as may be the case with a cantilevering column, the prestress has no destabilising effect on the cantilever (and may indeed provide a second-order stabilising effect) but it can cause buckling problems with the column considered as either pin-ended or pinned-fixed, depending on the precise detail at the support. If the void between the cable and the surrounding glass is filled with an appropriate material, forming a bonded tendon, then, as with toughened glass, the compressive forces induced in the glass are not destabilising.

10.2.2 Strength

Externally prestressed glass needs to be adequately strong, stiff, stable and robust. The principles governing its design are no different from those governing the design of glass columns, fins or beams, with attention paid to the effects of the precompression, particularly the accuracy with which it can be applied. Accuracy encompasses the precision of the applied force, its bearing onto the glass and the precision of its line of action.

Chapter 8 provides examples of the design of glass columns.

10.2.3 Deflection

Lateral deflection of columns is not usually a design criterion, unless it is associated with side sway of a building or of a storey within a building. Under those circumstances the engineer will want