1 Structural use of glass

1.1 Introduction

This Guide deals with the design of structural glass in buildings. This includes structural elements that carry load directly, such as a beam or column. It also covers glass elements that resist only wind load, their own weight, elements subject to thermal effects and those that support imposed loads/variable actions.

The use of glass as a structural material within buildings has become increasingly common over the past 25 years. As architecture becomes more adventurous (see Figure 1.1 and 1.2) and the need to create well lit and spacious areas within buildings becomes more prominent, the reliance on the use of glass as a structural material has increased.

This Guide is aimed at the structural engineer who is well versed in the design of building structures using more traditional materials such as steel and reinforced concrete, but is inexperienced in designing structural elements in glass. These could vary from balustrades to enclosures that are to be constructed entirely from glass.

The structure of this Guide is set out in such a way as to provide as many tools as possible to carry out the design of structural glass elements. However, it is not exhaustive and the reader is encouraged to seek further guidance from other texts.

The methods of design and construction of glass structures described in this Guide are contemporary to the time of its publication. Knowing that continuing research is being carried out in this field, the reader is alerted to the fact that the use of glass as a structural element is still benefiting from continued advancements and that there is much in the way of cutting edge technology that is being developed but not yet proven. It is for this reason that such research has not been included in this edition.

Since the first edition of this Guide was published in 1999, a significant amount of technological advancement has occurred within the realm of use of structural glass elements – see Figure 1.3 as evidence of this. It is this fact more than any other that has prompted the creation of this second edition.

The Guide is split into 14 chapters and has been set out in such a way as to aid the structural engineer to design, construct and inspect a glass structure. Chapters 2 to 4 explain design principles and criteria as well as expand on appropriate methods of computer modelling. The remainder of the Guide refers back to the principles laid down within these chapters, so the reader is encouraged to become fully versed with them before delving any further.

Chapters 5 to 8 describe how various structural glass elements are designed. Examples include balustrades, walls, floor plates, columns and beams. There is also an emphasis placed on the design of connections in all of their forms, be it bolted, silicone or adhesives within glass structures. The importance of connection design cannot be understated with respect to structural glass elements, as they play a significant role in the design of elements, far more so than for traditional building materials.

Chapter 9 covers the special application of glass structures, notably the use unique structural solutions such as the application of post tensioning.
2 Design principles

2.1 Glass material properties

This chapter sets out to define the guiding principles used when designing structural glass elements. These principles are based on contemporary texts and knowledge at the time of writing.

2.2 Behaviour of glass as a structural material

Glass behaves in a crucially different way from other, more familiar structural materials such as steel or aluminium. It does not yield and hence it is a brittle material. It fractures and its failure is difficult to predict.

To illustrate this further, Figure 2.1 shows the test results of the failure of 6mm thick basic annealed glass.

The tests were carried out in accordance with EN 1288-2 and show how stochastic (i.e. unpredictable) in nature the results are for glass. It should be noted that the distribution of glass failure that is shown on Figure 2.1 does not align with any probability distribution. It is for this reason that the Weibull probability density function is applied as proposed in EN 12600:2002. Additionally the coefficient of variation of strength for basic annealed glass is around 25% higher than for other more common structural materials.

Structural engineers designing steel structures have typically concentrated their attention on limiting stresses at places of maximum bending and shear. This is because steel can yield when it is subjected to localised areas of concentrated stress, due typically to lack of fit, and hence localised yielding is rarely considered during design of steel elements.

Conversely, designers cannot ignore stress concentrations and lack of fit when designing structural glass elements. It is for this reason that connection design is a core component when designing structures made from glass (see Figure 2.2).

Glass panes can deflect by more than their own thickness. This takes designers into the realm of large deflection theory (see Figure 2.3) which is unfamiliar territory for most structural engineers.

This theory is similar to applying $P\Delta$ effects and as such they can be applied when determining stresses in glass elements. Historically stresses in glass have erroneously been expressed as if small deflection theory were valid, using ad hoc methods, leading to the correct thickness. This gave rise to the use of unrealistic allowable stresses and typically led to the oversizing of glass elements by making them thicker than they needed to be. Quoted design stresses for use with small deflection theory will be larger than realistic design stresses used with large deflection theory.

Once the limitations of glass as a structural material are understood, then structural engineers have
6 Connection design

6.1 Introduction

This chapter builds on what was described in Section 2.4, which explains the various methods of support for structural glass elements. It considers what needs to be reviewed for each connection type.

For the purposes of design, connections can be split into two sub-categories: mechanical and adhesive-based. Mechanical fixings can be further split into clamp and bolt fixings.

6.2 Continuous linear support connections

Continuous supports provide an unbroken line of support along an edge of a glass pane (see Figure 6.1). While generally accurate for floor plates subject to a UDL action to consider the relative stiffness of the glass and supporting frame, for cladding elements it is more accurate to describe them as being supported off of a pair of discrete points. These support points are setting blocks, which the glass sits upon once it is installed. These blocks transfer the self-weight of the glass to the supporting frame.

The localised stresses generated by these setting blocks are not normally a significant concern as they only typically support the self-weight of the glass panes. Nevertheless there are instances where for particularly large panes of glass both the compressive capacity of the setting blocks and any localised tension stress due to the bridging of the glass over the setting blocks needs to be addressed.

These capacities are dependent upon the elastic modulus of both the setting block and the pane of glass. It is possible therefore to review the impact of the size of setting blocks within a continuous linear support system.

The sizing of setting blocks can impact on the integrity of the glass pane they are supporting. As a general rule the width of setting blocks should be equal to the glass pane thickness. For more information refer to BS 6262: 1 2005 Glazing for buildings – General methodology for the selection of glazing for sizing6.1 and BS 8000:7 1990 Workmanship on building sites. Code of practice for glazing6.2 for installation guidance.

6.3 Clamp connections

Clamps can either be continuous or small, localised fixings.

Unlike the continuous support systems described in Section 6.2, clamps can provide a positive fixing that does not rely entirely on gravity, i.e. they have a tension capacity as well as shear and compression.

They can have setting blocks present, which creates the same issues as described in Section 6.2, but for the smaller clamps the primary point of concern is the local bending and stiffness of the clamp itself as it interacts with the glass it is supporting. The stiffness of supports is discussed in Chapter 4 with respect to computer modelling, but the same issue holds true for small clamps. If they are relatively stiff compared to the glass panes they are supporting, then localised bending stresses can develop around the clamp. It is these stresses the glass has to be designed for. In many cases this can govern the design more than the overall element itself (see Figures 6.2 and 6.3).

It is therefore important to determine the relative stiffness of the clamp against the glass pane it is supporting. Once that is established the bending stresses around the clamp can be determined and an analysis can be carried out. The applied stresses are compared against the design strength of the glass as described in Chapter 3. Additionally, to minimise the effects of local stresses, soft bearing pads can be used within the clamp assembly. However, such pads have the tendency to cause the pane they are supporting to unduly deflect.

6.4 Friction connections

Friction grip connections are a subset of clamping connections and are more often than not found in splice connections within beams and columns. They transfer in-plane forces without needing the bolts to bear on the glass. Therefore attention needs to be paid to the local stresses around the bolts that pass through the clamp. The hole around the bolt is oversized to accommodate the inclusion of a hard isolation material, as described in Section 2.4. The following procedure can be used to design splice connections using the estimated size and number of bolts within a splice. The principle behind it focuses