Adapting Glass to Lightweight Structures

Richard K. Rumbel,
Sales & Marketing Director.
ARCHITECTURAL GLASS PROJECTS PTY. LTD.

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1. USEAGE

Lightweight structures have been around for a long time. One of the most common applications would be aeroplanes. It was probably due to this technology that air warfare was practised, and it kept the ”tiger moth” flying for almost 60 years.

In designing a lightweight glass structure the whole concept is almost contradictory. However glass, due to its transparency, gives the impression that it is not there and therefore focus is brought upon this support structure.

Possibly the most visual lightweight looking structure is the toughened glass suspended or stacked assembly. In practice this is not a lightweight structure as it uses quite large and robust glass supporting beams but being transparent it doesn’t seem to be there giving the effect of being lightweight.

In recent times there has been a wide trend to use tension wire trusses and to support glass walls and roofs using this method. This allows the use of steel rods, or cables to form the tension member within the truss, and usually the glass forms the compression member. In this situation the risk is that under reverse conditions should the glass break there is very little to maintain the rigidity within the truss this necessitates tension cables or wires acting in tension both ways. If you are designing a roof the glass helps to preload the system thus allowing a little latitude in the structural design.

Another method of producing a lightweight structure is to use the spaceframe as the support. Spaceframes are a very effective method of supporting large loads particularly effective over large spans.

With any support structure people have different thoughts about its suitability. When glass is used in a structure it has the disadvantage that it will have to be cleaned. Tension wire trusses and spaceframes are the great hinderer of the cleaner. They present a real obstacle in getting close enough to clean the glass in an effective way.

In the contracting role we face many ways to secure to different support structures. Then to compound the problems the architect will want to adapt countersunk fixing methods. Countersunk fixings have the honour of being the worst method by which to fix glass. Countersinking bolts into the glass stresses glass more highly than any other fixing method I know.

It is not unusual to create stresses as high as 40 MPa using the countersunk methods. Countersinking the fixings require fixings at intervals not greater that 1500mm centres this necessitates a more cluttered structure as it needs to be rigid to apply a uniform load to the glass.

In our office we use a rule of thumb design check when it comes to the installation of glass to a structure. In deflection fully toughened glass can deflect as much as span over 40 with safety, however if glass is to be installed onto a structure and if the structure can deflect so that the glass would have to elongate at all – then the installation cannot be made as glass cannot accept this level of stress.

- When glass is under stress, it deforms to a certain extent then stops. There is no further deformation or creep with time.
- Glass is not subject to dynamic fatigue (from cyclic loading). The perfect linearity of its stress/strain curve means that reversals of stress leave the glass unchanged; for example no work hardening can occur.
- Glass does not suffer from permanent deformation. When a stress is removed the glass returns to its original shape, no matter how long the glass has been in stress.
- The absence of any plastic deformation leads to susceptibility to local overstressing (due to its inability to yield locally) and a vulnerability to flaws.

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Steel structures for example can accommodate local stresses and redistribute them by small plastic deformations; thus the structure is very ”forgiving”. Glass cannot do this. Glass deforms elastically up to the point where the interatomic bonds break. If there is enough stress applied then a crack will develop and failure will occur. If there is a flaw in the glass even a Griffith flaw then the glass can fail earlier in its strain curve.

My personal preferences is the use of patch fittings to secure toughened glass to a structure as they tend to distribute the stresses over a larger area. A 65mm round patch fitting in my book is 10 times safer than a 20mm countersunk fixing.

1. At Governor Philip Tower we used tension wire trusses to support the glass. The tension wires are quite taut and in its complete form it is the basis of a sound structure (although the system produces almost harplike notes when plucked).

2. At Darling Park we installed glass into a lightweight structure made up of 65mm diameter x 1.6mm thick stainless steel tubes set on either side of the glass to produce a vehedral effect. This structure was lightweight and whilst the glass was contained by 65mm diameter patch fittings stresses within the glass never reach more that about 35 MPa at peak design load.

3. At Zenith Centre we installed glass onto a spaceframe. This structure utilised patch fittings as the method of securing glass. This particular structure should never stress the glass beyond about 30 MPa at the fixing points.

Throughout this presentation so far I have considered only the use of heavy toughened glass. If you consider other glass there are other problems that enter the equation, these being:–

1. The lack of tensile strength of annealed glasses.
2. Thermal stresses caused by the glass absorbing radiated heat.
3. Glazing methods used for containing the glass.

Often I am asked what is the safest method for glazing. I would have no hesitation in saying that to my mind structural silicone is the safest technique as far as the glass is concerned, as the glass effectively floats on a bed of fairly soft rubber. I have tested the stresses applied by structural silicone versus mechanical restraining techniques. My experience is that the same piece of glass restrained in an aluminium mullion glazing system failed at 4.8 KPa and in the structural silicone system the glass remained intact at 5.7 KPa. However structural silicone remains a fairly untried medium and I am aware of many failures attributed to silicone, however this remains another subject.

In a cable truss or a lightweight structure it is not easy to adapt these glazing methods readily, however generally there is a way to use glass. Although it may require some very accurate and close analysis. Often all that may be required is a pin or hinge to be introduced into the system to relieve the concentration of stresses.

The codes for design and general practice would dictate that glass should not be stressed beyond 50 MPa at peak design load in the use of toughened glass. All fixings need to be designed with this in mind.

It is paramount to keep in mind that glass can and will fail. At all times glass structure designs should always contain a design parameter that any piece of glass can break due to reasons other than mechanical impact or overstressing. All toughened glass has the potential risk of spontaneous breakage from nickel sulphide inclusions. At this point I should say that even toughened glass that has been heat soaked still fails due to nickel sulphide seeds within the glass.

Laminated glass or annealed glass will overcome problems associated with spontaneous breakage, however these glasses are inherently weaker than toughened glass and therefore need to be supported in a framed glazing system, aluminium being the most common choice. When using bars rods cables or wires this can shadow laminated glass if there is support structures outside. Shadows can cause breakage due to thermal stresses.

Generally laminated or annealed glasses are not used in these types of installations although there are occasions where laminated toughened glasses are used. This practise is a little frightening as if any type of failure takes place you end up with a large heavy floppy mass that will almost cause certain injury if it falls and hits somebody. Generally in a failure there is not enough strength left in the P.V.B. laminate to hold the glass into the opening.

Designing this way particularly in truss systems that are subject to a lot of movement places a lot of demands upon the glass.

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2. CONCLUSION

In conclusion I would like to stress that with lightweight structures two problems need to be considered, these being:–

1. That during the life of the structure a glass failure will take place and that a replacement will need to be made.

2. The glass will need to be cleaned and with Workcover becoming more stringent in their requirements this is starting to become a real problem.

So consider these restrictions when you design, the project may not proceed if these criteria cannot be satisfied fully.

Finally can it be built?

12mm toughened glass weights 30kg per square metre and this makes a 2.4 mete wide x 4.0 metre high piece of glass a 1/4 of a tonne heavy, today men cannot lift this size piece of glass.

3. REFERENCE

1. Glass in Buildings – Button & Pye
2. Design Forums – Zenith Centre, Darling Park, QV1 Perth, Governor Philip Tower

With thanks to the staff at Architectural Glass Projects and Miller, Milston & Ferris.

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