GUARDS & BARRIERS 4D CALCULATION TECHNIQUES

Since the withdrawal of BS 6180:1999 [1] and its replacement with BS 6180:2011 [2], Table 2 (S*izes of fully framed single glass panes in accordance with the design criteria given in BS 6399-1:1996*) is no longer available, and as such, pre-set limits on pane area allowances based on design criteria and glass thickness are no longer available. As a result, to determine suitable glazing thicknesses, calculations should be carried out where physical testing does not take place.

CALCULATION METHODS

There are several methods that can be used to calculate the stress and deflection present in glass panes under loading, with varying degrees of accuracy;

- Linear plate theory,
- Non-Linear plate theory
- Linear Finite Element Analysis
- Geometrically Non-Linear Finite Element Analysis

PLATE THEORY

The theory behind calculating the bending of plates and shells is based on Kirchhoff-Love and Mindlin-Reissner plate theories. Kirchoff-Love plate theory is an extension of Euler-Bernoulli beam theory, whilst Mindlin-Reissner is a further extension on this.

Linear plate theory is reasonably accurate whilst the amount of deflection of the plate is small relative to the plate thickness. As deflection increases beyond the plate thickness, typically a deflection greater than half glass thickness, the deformation, and as such, calculated stress increases excessively compared to real-world conditions. As such, the validity of these calculations to glass plates under loading is limited.

In order to compensate for the inaccuracies generated under larger deflections, non-linear plate theory can be used, which in some cases utilises factors based on flexural rigidity, where a plate will resist deflection whilst undergoing bending. Non-linear plate theory also forms the basis of the calculation method set out in prEN 13474:2009 [3] for deflections under distributed (wind) loads. Depending on the method used, this will typically, for rectangular plates, provide a reasonable level of accuracy. However, the calculations are only typically valid for rectangular simply supported plates.

There are also limitations for glazing with multiple layers, specifically laminates. For laminated glasses, effective thickness calculations can be carried out based on interlayer properties, however, it is more accurate to model the laminate using finite element analysis (FEA).

FINITE ELEMENT ANALYSIS

FEA involves dividing a structure into finite elements and nodes in order for each one to be analysed with considering to neighbouring elements or boundary conditions. The calculations are still, to some degree, based upon Mindlin-Reissner plate theory, but by subdividing the plate.

The FEA methodology allows greater flexibility with regards to shapes and fixing methods, and as such, allows the calculation of stresses and deflections in panes with complex support conditions and/or shapes.

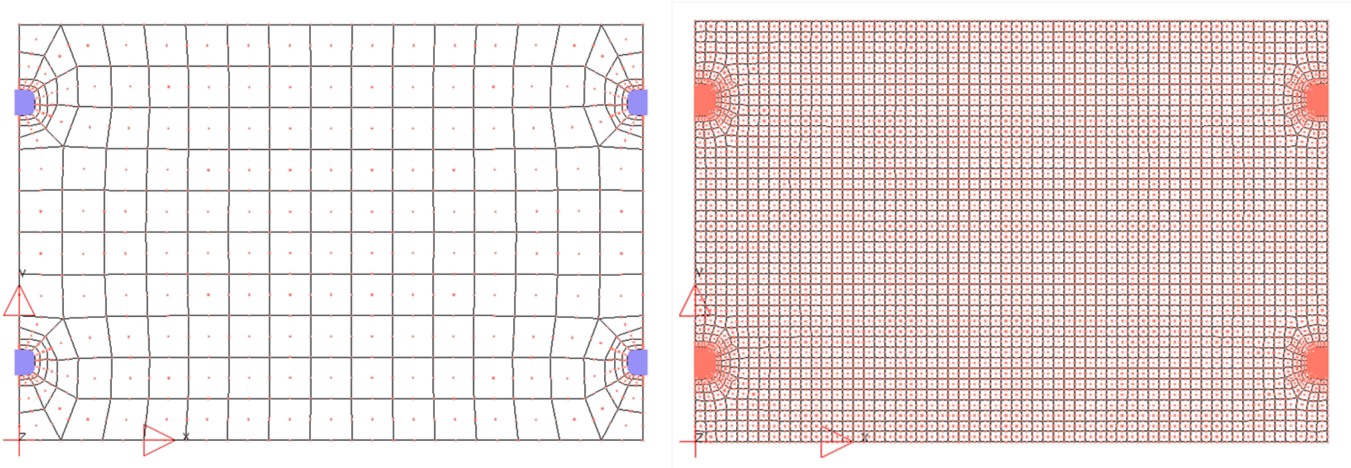

Figure 1 - Mesh generated using FEA

The above image shows a clamped glass panel, with the mesh generated. The mesh is generated around the clamps to allow more accurate analysis of the stresses and deflections in these areas. Software such as Mepla, allows flexibility with the mesh refinement, with the image on the right showing smaller element sizes, and as such, greater accuracy for calculation. The below images show the mesh refinement and associated stress from the calculation of the plate under concentrated loading.

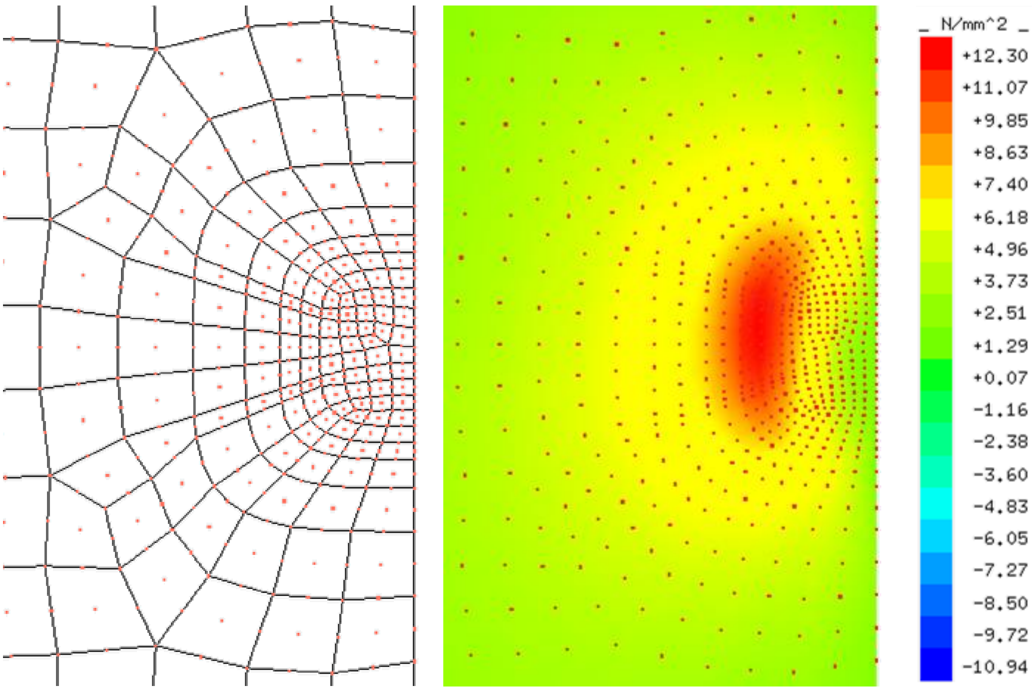

Figure 2 - Mesh refinement and stress concentrations determined with FEA

GEOMETRICALLY NON-LINEAR CALCULATIONS

Some FEA software, including Mepla, allows analysis using a geometrically non-linear calculation approach, which considers membrane stresses in the glass. This will typically be expected to yield more accurate results for panes under larger deflections, as with non-linear plate theory. This is discussed in more detail in **Glass Fundamentals 2A**.

REFERENCES

[1] British Standards Institute, *BS 6180:1999 - Barriers in and about buildings. Code of practice,* BSI, 1999.

[2] British Standards Institute, *BS 6180:2011 - Barriers in and about buildings. Code of practice,* BSI, 2011.

[3] European Committee for Standardization, *prEN 13474-3:2009 - Glass in building - Determination of the strength of glass panes - Part 3: General method of calculation and determination of strength of glass by testing,* CEN, 2009.