GUARDS & BARRIERS 4C LIMIT STATE DESIGN VS. PERMISSIBLE STRESS

Whilst limit state design now forms the basis of Eurocodes and structural design in Europe, the adoption of these methodologies with glass is still not complete in all countries. As such, permissible stress design is still used for the determination of initial glass specification prior to a full structural analysis being carried out. This is especially the case in the UK.

Whilst documents are available that detail the different design methodologies, this document provides a worked example of a glazing unit under personnel loading in order to compare the methods in question. This will consider the both ultimate limit state (stress) and serviceability limit state (deflection).

GLAZING UNIT

For this worked example, a double glazed unit is under consideration for installation within an office building;

Table 1 – Worked example design parameters

Parameter	Value
Width	1500 mm
Height	2500 mm
Inclination	90º from Horizontal
Internal Pane	8.8 mm STADIP PVB Laminated Glass
Cavity	16 mm (Argon)
External Pane	6 mm Thermally Toughened PLANICLEAR Float Glass
Edge Support	Four Edge Linear Simply Supported

LOAD CONDITIONS

As full height glazing, and as such acting as a barrier, the glazing must be able to withstand applied personnel and environmental loads, as per BS 6180:2011 [1];

Table 2 – Worked example load conditions

Parameter	Value
Uniformly Distributed Line Load	740 N/m
Concentrated Infill Load	500 N
Uniformly Distributed Infill Load	1000 N/mm^2
External Wind Pressure	1250 N/mm^2

In addition to personnel loads and wind pressure, cavity pressure loads are also being considered, based on the following “Winter” environmental conditions from DIN 18008-1 [2] and TRLV [3], the effects of which are calculated by the software;

Table 3 – Worked example cavity loads

Parameter	Value
ΔT ($T_{Ambient} - T_{Manufacture}$)	-25 K
Cavity Pressure	0.099 N/mm^2
Ambient Pressure	0.103 N/mm^2
Difference in Altitude	-300 m

EFFECTS OF ACTIONS

Due to the wind load being external pressure, and so favourable when considering the internal personnel loads, these are factored out in limit state design ($\gamma_{Q,i} = 0$ when favourable), and excluded as an associated action under permissible stress design.

For the below example, only the line load will be considered, however, the same parameters would apply to the concentrated and UDL infill loads.

LIMIT STATE DESIGN – EFFECT OF ACTIONS

For limit state design, the load combination, as per EN 1990:2002 [4, 5] is considered, as below;

(Case A): $$E_{ULS,d} = E\{\gamma_{G,j} \cdot G_{k,j} + \gamma_P \cdot P + \gamma_{Q,1} \cdot Q_{k,1} + \textstyle\sum_{i>1}(\gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i})\} \quad j \geq 1; i \geq 1$$

These yield the following load cases;

(Case A) $$E_{ULS,d} = E\{1.35 \cdot (\Delta H\ Pressure) + 1.50 \cdot (Line\ Load) + 0.90 \cdot (\Delta T, \Delta P\ Pressure)\}$$

PERMISSIBLE STRESS – EFFECT OF ACTIONS

For permissible stress, the relevant loads in this case are un-factored, yielding the following load combinations;

(Case B) $$E_{ULS,d} = E\{(1.00 \cdot \Delta H\ Pressure) + 1.00 \cdot (Line\ Load) + 1.00 \cdot (\Delta T, \Delta P\ Pressure)\}$$

RESISTANCE TO THE EFFECTS OF ACTIONS

The resistance is calculated based on partial or global safety factors as discussed in associated documents. For this example DIN 18008-1 is used for determination of the resistance of glass with regards stress. Permissible stress limits are considered with TRLV guidance.

LIMIT STATE DESIGN – RESISTANCE TO THE EFFECT OF ACTIONS

The following equations apply for determination of the resistance;

Annealed Glass: $$R_{d;A} = \frac{k_{mod} \cdot k_c \cdot f_{g;k}}{\gamma_{M;A}} \cdot f_{vsg} \cdot f_e$$

Pre-Stressed Glass: $$R_{d;v} = \frac{f_{g;k}}{\gamma_{M;v}} \cdot f_{vsg}$$

Where;	k_{mod}:	factor for load duration
	k_c:	construction coefficient
	$f_{g;k}$:	characteristic value of the bending strength of glass
	$\gamma_{M;A}$	material partial factor for annealed glass
	$\gamma_{M;v}$	material partial factor for pre-stressed glass

Additional factors are also considered for glass within a laminate construction and where a free edge is present (annealed glass only). The laminated glass factor (f_{vsg}) is applied if the Young's modulus is less than the foil stiffness limit for shear, and increases the glass strength by 10%. Where annealed glass has a free edge under tensile stress, the glass strength is reduced to 80%.

Based on this, the following resistance values are calculated;

Table 4 – Limit state design ultimate limit state values

Pane	Glass Type	R_d
Internal	Laminated Annealed Float Glass	34.65
External	Thermally Toughened Float Glass	80.00

PERMISSIBLE STRESS – RESISTANCE TO THE EFFECT OF ACTIONS

Based on TRLV guidance, where climatic loads are considered and the glazing is within an insulating glass unit, a factor of 1.15 is applied to the permissible stress (1.25 if the pane area is less than 1.6 m^2). As such, the following resistance values are calculated;

Table 5 – Permissible stress limits

Pane	Glass Type	R_d
Internal	Laminated Annealed Float Glass	25.87
External	Thermally Toughened Float Glass	57.50

ULS LOAD CASE RESULTS

Based on the effects of actions of the load cases, and associated resistance to actions, the following results are achieved through calculation with MEPLA Version 4.0.3, where E_d is calculated stress and R_d is the allowable stress;

Table 6 – Limit state ULS load case results

Load Case	Inner (Laminated)			Outer (Toughened)		
	E_d	R_d	%	E_d	R_d	%
A	18.35	34.65	53.0	6.12	80.00	7.6
B	14.20	25.87	54.9	3.97	57.50	6.9

The percentage column shows the level of the resistance the effect of the action has reached, which allows a more relevant comparison of the different methodologies.

Although the resistance of the laminated glass is higher when calculating with limit state design, which may make it seem less conservative, the imparted loads, also being factored result in a higher level of stress, resulting in a comparable percentage of the resistance reached.

SERVICEABILITY LIMIT STATE

The allowable deflection limits under SLS conditions are defined by BS 6180:2011, and as such remain the same under permissible or limit state design conditions. However, the applied loads will still be factored depending on the method used, which will influence the level of deflection calculated.

For limit state design, the following formula can apply;

(Case C): $E_{SLS,d} = E\{G_{k,j} + P + Q_{k,1} + \sum_{i>1}(\psi_{0,i} \cdot Q_{k,i})\} \quad j \geq 1; i \geq 1$

Which yields;

(Case C): $E_{SLS,d} = E\{1.00 \cdot (\Delta H\ Pressure) + 1.00 \cdot (Line\ Load) + 0.60 \cdot (\Delta T, \Delta P\ Pressure)\}$

For permissible stress, as previously;

(Case D) $E_{SLS,d} = E\{(1.00 \cdot \Delta H\ Pressure) + 1.00 \cdot (Line\ Load) + 1.00 \cdot (\Delta T, \Delta P\ Pressure)\}$

SLS LOAD CASE RESULTS

Where E_d is calculated deflection and C_d is the allowable deflection, where E_d is calculated deflection and C_d is the allowable deflection;

Table 7 – Limit state SLS load case results

Load Case	Inner (Laminated)			Outer (Toughened)		
	E_d	C_d	%	E_d	C_d	%
C	10.71	25.00	42.8	4.78	25.00	19.11
D	11.26	25.00	45.1	3.95	25.00	15.78

As before, the percentage column shows the level of the resistance the effect of the action has reached. In the case of deflection, this is shown to be similar under permissible stress and limit state design with regards to both the internal and external panes.

REFERENCES

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

[2] Deutsches Institut für Normung, *DIN 18008-1:2010-12 - Glas im Bauwesen - Bemessungs- und Konstruktionsregeln - Teil 1: Begriffe und allgemeine Grundlagen,* Beuth, 2012.

[3] Deutsches Institut für Bautechnik, *Technische Regeln für die Verwendung von linienförmig gelagerten Verglasungen (TRLV),* DIBt, 2006.

[4] European Committee for Standardization, *EN 1990:2002 - Basis of structural design,* CEN, 2002.

[5] European Committee for Standardization, *NA to BS EN 1990:2002+A1:2005 - UK National Annex for Eurocode - Basis of structural design,* BSI, 2002.

[6] Österreichisches Normungsinstitut, *ÖNORM B 3716-1 - Glas im Bauwesen - Konstruktiver Glasbau - Teil 1: Grundlagen,* Baudatenbank, 2013.

[7] Vlakglas, *NEN 2608:2014 - Vlakglas voor gebouwen - Eisen en bepalingsmethode,* NEN, 2014.

[8] European Committee for Standardization, *EN 1991-1-1:2002 - Eurocode 1. Actions on structures. General actions. Densities, self-weight, imposed loads for buildings,* CEN, 2002.

[9] European Committee for Standardization, *EN 1991-1-3:2003+A1:2015 - Eurocode 1. Actions on structures. General actions. Snow loads,* CEN, 2003/2015.

[10] European Committee for Standardization, *EN 1991-1-4:2005+A1:2010 - Eurocode 1. Actions on structures. General actions. Wind actions,* CEN, 2005/2010.

[11] European Committee for Standardization, *EN 572-1:2012 - Glass in building. Basic soda lime silicate glass products. Definitions and general physical and mechanical properties,* CEN, 2012.

[12] European Committee for Standardization, *EN 1863-1:2011 - Glass in building. Heat strengthened soda lime silicate glass. Definition and description,* CEN, 2011.

[13] European Committee for Standardization, *EN 12150-1:2015 - Glass in building. Thermally toughened soda lime silicate safety glass. Definition and description,* CEN, 2015.

[14] European Committee for Standardization, *prEN 16612:2013 - Glass in Building - Determination of the load resistance of glass panes by calculation and testing,* CEN, 2013.

[15] 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.