BALANCING COST, RISK AND RELIABILITY FOR STRUCTURAL USE OF GLASS

BALANCING RISK, RELIABILITY, POST-DAMAGE BEHAVIOR AND DESIGN EFFICIENCY IN STRUCTURAL USE OF GLASS

Glass is unique as a building material. In the past, glass suddenly breaking and material dislodging from a building exterior has been considered an acceptable risk for the benefits of transparency and durability that it offers. The same perceptions of sudden failure have, however, limited the structural use of glass, despite its excellent compressive strength and understood tensile strength characteristics.

As cracks in the glass interrupt the transparency and are perceived as initiation of potential fallout, design without cracks is considered a requirement. Some design practices are based solely around preventing initial cracks to achieve overall reliability, ignoring the behavior after cracking. However, in a material where failure is often caused by extraordinary events or installation errors rather than excessive design loads, this only increases the initial sizing and cost. Controlling the failure mode and engineering the post-damaged condition is more effective prevention of unacceptable outcomes. Modern glass design utilizing laminated glass allows us to better understand and control the behavior of the glass systems in the undamaged, partially-fractured and fully-fractured states.

This poster examines the balance of load and strength to prevent initial damage due to design loads and how this should be influenced by the behavior of the system in the post-damaged state. The priority given to preventing initial failure needs to be proportional to the consequence of that failure. The design strategy recognizes that circumstance and consequence influence design. Another standard that deals with building materials in the damaged state is the SEI/ASCE 7 seismic provisions. Similarly, the post-damage perfomance is based on the system behavior and not individual elements. It also recognizes that what may be good design for glass in some locations is not good design in others; that it will be further influenced by the occupancy in the proximity of the glass.

Glass risk categories account for the anticipated occupancy and the level of post-damage behavior and capacity desired by the designer or specifier. The glass risk categories can be characterized as follows: **G-I**, very low occupancy and few requirements; **G-II** typical applications in which some detachment or limited fall heights may be acceptable; **G-III** where there is a significant risk to human life or to cause injury or economic impact (generally higher occupancy) and it is desired to have the glass retained in position, possibly with some post-damage capacity; **G-IV** where the glass is essential to the facility and requires a specified level of function in the damaged state. In addition to the post-damage behavior requirements, the Reliability Adjustment Factor G_R adjusts the capacity of the glass to achieve desired performance for design loads.

Each scenario takes into the consideration the: occupancy (Glass Risk Category); usage (Infill, Secondary or Primary Structure); orientation (angle to vertical) and presence of people on or under the glass. Each line has multiple compliance options, of which only one needs to be satisfied, each of which has a reliablity adjustment factor as a function of the compliance path and behavior selected.

The target reliablity has loose parallels with ASCE-7 Table 1.3-1 Target Reliability (Annual Probability of Failure, Pf) and associated Reliability Indices (ß) for “Load Conditions that Do Not Include Earthquake, Tsunami or Extraordinary Events.” In doing so, there is some indexing between the proposed standard for Structural Use of Glass and the principles in standards for other more traditional building materials.

The proposed strength model in the ASTM Structural Use of Glass Specification is similar to the one outlined in the draft for Eurocode 11. It has a default reliability index, ß, of approximately 3.4~3.5 , which is similar to the ASCE-7 Table 1.3-1 requirement for Building Risk Category II for a failure mode that is “either sudden or leads to widespread progression of damage.” The Glass Risk Category follows the similar principles to the ASCE/SEI 7 Building Risk Category, balancing reliability with circumstance and consequence, but it is based on the occupancy in the proximity of the glass and may vary within a building according to the use of the glass.

Window glass is traditionally designed for a probability of failure (PoF) of $8x10^{-3}$/50yr or an annual PoF of $\sim 1.6x10^{-4}$ which is close to ß=2.5. This is the lowest of the reliability indices in the ASCE table, which recognizes that window glass is not being used to hold up other parts of the structure. Other influences include AAMA and GANA which suggests that a PoF of $1x10^{-3}$ is appropriate for overhead glazing and IBC, which calls for a ‘design factor’ of 4 for glass balustrades as based in AAMA CW-12-84 . NCSEA states that PoF 1x10-3 for AN glass with a coefficient of variation (CoV) of approximately 24~25% equates to a design factor of 4.

The new standard for glass is based on LRFD principles, with partial factors for loading and strength. Factors for loading and their combinations are covered by ASCE 7 and guidance is provided for material partial safety factors in C2.3-2

$$\Phi = (\mu_R/R_n) \exp(-\alpha_R.\beta.V_R)$$

in which μ_R = mean strength, R_n = code-specified strength, V_R = coefficient of variation (CoV) in strength, and α_R = sensitivity coefficient, equal approximately to 0.7. For annealed glass, using a mean strength and rated strength of 45MPa (6,500psi), a CoV of 25% and ß=3.4, results in Φ=0.55 (or $\gamma=1/\Phi=1.8$).

The Reliability Adjustment Factor, G_R, adjusts the basic strength model to the target reliability for circumstance and consequence of the structure and the damaged behavior justified by the designer. Within each category there may be several options for justification, of which only one is required to be justified. The reliability required in the undamaged state, G_R, is a function of the behavior in the damaged state.

As heat-strengthened (HS) glass and fully-tempered (FT) glass have coefficients of variation (CoV) of 15% and 10% respectively, the adjustment factor is also a function of the kind of glass and is tabulated based on a code letter, from A to H representing “ß”=2.5 to “ß”=4.5. For AN glass G_R is greater than 1 for “ß”>3.4 and less than 1 for “ß”<3.4. For HS the delineation is “ß”=4.1 and for FT G_R is always less than 1.0. This recognizes that HS and FT glass have lower CoV and that the surface RCSS used in calculations is a minimum with the mean exceeding the rated strength. (Note the table 1.3-1 in ASCE7 includes importance factors manipulating the loading side of the equation to achieve the overall PoF, so here “ß” is not the true reliability index and cannot be related directly to the overall probability of failure for building risk categories other than II.)

It is worth noting that the ratio of $G_{R.\beta=4.18}$ / $G_{R.\beta=2.5}$ is 1.34, and the strength ratio of allowable stress PoF of 8:1000 vs 1:1000 per ASTM E1300-16 eqn X6.1 is 1.34; so, there is good agreement of this method with AAMA/GANA recommendations and IBC requirements.

Drawing parallels between ASCE7 Table 1.3-1 and the glass risk classes, the following principles were used as guides:

- “Failure that is not sudden and does not lead to widespread progression of damage” equates to favorable failure modes; the favorable post-damage being satisfying post-damage loading such as satisfies post-damage loading with all plies broken (Retained).
- “Failure that is either sudden or leads to widespread progression of damage” corresponds to the post-damage condition where a ply is damaged but does not lead to further breakage under post-damage design loads (NFB).
- “Failure that is sudden and results in widespread progression of damage” equates to less favorable outcomes where Glass may dislodge from support system on 1 or more edges, but cannot fall through a publicly trafficable space with a swing arc of 2.1m (7ft) above a trafficable surface (No Fall); or where fall of the glass has limited consequence and has no post-damage requirement (NR).
- As with the ASCE-7 seismic requirements (which also address post-damage detailing) there are certain structure types which have height limits or are not permitted.
- For secondary structure the outcome for a given glass risk category is a similar column to the equivalent building risk category.
- For infill elements, the risk is considered less and the glass target reliability ß, is notionally one column to the left in ASCE table1.3-1.
- For primary elements, the brittle nature of glass is taken into consideration and the glass target reliability ß, is notionally one column to the right in ASCE table1.3-1.
- Stacked glazing is an infill element, but is regarded as dead load bearing hence is treated as a primary element.
- Elements that support live load or act as barriers require ß=4 or greater regardless of risk class. (Although, we note that these requirements were written at a time when monolithic glass was common.)
- Failure modes without consequence have ß=2.5 per common practice.
- Post-damage condition uses ß=2.5 for all cases (companion event after damage and the fractured panel continues to contribute to strength), so where specifically required, the post-damage load factor is greater than 1.0.
- ASCE-7 also adjusts the load side of the equation in accordance with Building Risk Classification.

The risk classification provides a system of requiring minimum tensile reinforcement with interlayer and the reliability index adjustment factor aims to balance performance, risk and cost.

The rules, along with the strength model and imperfection and stability sections, are currently being benchmarked and calibrated. If you are interested in providing feedback, please email Richard Green at **Richard@GreenFacadesLLC.com**

Acknowledgement and Caveats

The opinions expressed in this paper are those of the author and may not represent the consensus position of the ASTM Committee or represent the final terms adopted by the Standard. They should not be used for design. The purpose of this paper is to propose a design method for comment and benchmarking/calibration prior to incorporation in the Standard.

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References

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3. Green – Glasscon Global 2018, “Century Project Glass Design - Opening the Aperture” www.glassconglobal.com
4. AAMA Volume 4, Part 3, page 7
5. GANA Glazing Manual, 50th Anniversary Edition P59
6. International Building Code 2015 2407.1.1
7. AAMA CW 12-84 Structural Properties of Glass
8. NCSEA Engineering Structural Glass Guide S3.5
9. ASTM E1300-16 Standard Practice for Determining Load Resistance of Glass in Buildings

Table notes

1. Overhead, access only with fall arrest devices and access equipment that does not rely on the glass for support. For systems that use glass for access support see section >60 deg.
2. Glass with barrier load and >30” drop beyond barrier must satisfy this line in addition to the relevant condition line.
3. Potential maintenance access only without arrest or access device. Where an access device is required to be used that does not rely on the glass for support the <60 degree conditions may be used.
4. Must satisfy this in addition to applicable condition.
5. Refer to Table 7.4 for loading durations.
6. Refer to Table 7.5 for G_R values based on the code below.
7. For post-damage condition refer to Table 7.5 code “A” for G_R.

GC	Elements	Description	Design Requirements: Height Limit (fall	Retention	Redundancy	# Plies Broken	In Service Reliability Adjustment Factor G_R	Dead D: C_{PD-D}	Dead D: Duration	Variable [5]: C_{PD-VL}	Live L: C_{PD-L}	Live L: Duration	Comments
GLASS RISK CATEGORY G-I	INFILL	Glass within 15 degrees of vertical	NL	NR	NR	NR	A	NR		NR	NR		
		Overhead Glazing (>15 degrees of vertical)	10ft	NR	NR	NR	A	NR		NR	NR		
			NL	No Fall	NR	All	A	1	1 hr	NR	NR		
			NL	Retained	Yes	1	A	1	1 w	0.2	NP		
	SECONDARY	Glass within 15 degrees of vertical	NL	NR	NR	NR	A	NR		NR	NR		
		Overhead Glazing (>15 degrees of vertical)	10ft	NR	NR	NR	A	NR		NR	NR		
			NL	No Fall	NR	All	A	1	1 hr	NR	NR		No Fall of supported elements
			NL	Retained	Yes	1	A	1	1 w	0.2	NP		
	PRIMARY	Not Permitted	NP										
GLASS RISK CATEGORY G-II	INFILL ELEMENTS: GENERAL	Glass not over trafficable area and not trafficable without fall arrest device	10 ft	NR	NR		A	NR		NR	None	NR	Heat Soak recommended for FT > 10ft
			18 ft	NR	NR		A	NR		NR	NR		
			NL	No Fall	NR		A	1	1 w	NR	NR		
	VERTICAL	Glass with unsupported and unsealed vertical edges	10 ft	NR	NR		A	NR		NR	NR		Heat Soak recommended for FT >10ft
			18 ft	NR	NR		B	NR		NR	NR		
			NL	No Fall	NR		A	1	1 w	NR	NR		
			10ft	NR	NR	NR	A	NR		NR	NR		
		Doors	13ft	NR	NR	NR	B	NR		NR	NR		
			NL	No Fall	NR	All	A	1	1 w		NR		
			NL	Retained	Yes	1	A	1	1 w	0.2	NR		
	<15 deg from vertical without barrier loads	4 sided supported windows and 2/3 side supported windows with structural silicone seals to unsupported edges	NL	NR	NR		A	NR		NR	NR		Refer E1300/IBC for alternative methods
		Glass with unsupported and unsealed edges <15 deg from vertical and	10 ft	NR	NR		A	NR		NR	NR		Heat Soak recommended for FT>10ft
			18 ft single	NR	NR		B	NR		NR	NR		Cordon off area when boom-lift or mechanical access device in use
			Top Hung	NR	NR	All	B						fire baffles - specific exclusion in foot note
			NL	No Fall	Yes	All	B	1	1 w		None	NR	
			NL	Retained	Yes	1	B	1	1 w	0.2	None	NR	
	<30 Deg from Vertical	Fully Tempered Safety Glass	10 ft	NR	NR		A	NR		NR	NR		or as required by the relevant building code
		Residential <3/16" FT mono Area <16 ft^2	12 ft	NR	NR		B	NR		NR	NR		Only where permitted by the relevant building code
	<60 deg from Vertical (NOTE 1)	4/3/2/1 sided supported glass	NL	NFB	Yes	1	B	1	1 w	0.2	0.5	10 min	0.5 because longer to be noticed/replaced
			NL	No Fall	NR	All	D	1	1 w				Verification test needed?
			NL	Retained	Yes	All	A	1	1 w	0.2	None	NR	ASCE C2.5.2 extraordinary events
	Barrier (<60 Deg from vertical) (NOTE 2)	Glass with barrier load >30" drop beyond barrier	NL	NFB	Yes	1	F	1	1 w	0.2	0.5	1 min	If there is a potential for injury (>30 drop beyond barrier) then there needs to be post failure capacity.
			10 ft	NR	Alt Path	All	F	1	1 w		0.5*	1 min	A rail capable of bridging the potential opening satisfies redundancy requirements. *load on alt path
			NL	No Fall	Alt Path	All	F	1	1 w		0.5*	1 min	A rail capable of bridging the potential opening satisfies redundancy requirements. *load on alt path
			NL	Retained	Yes	All	D	1	1 w	0.2	0.5	1 min	Less than <4" opening
		Glass with barrier load <30" drop beyond barrier	10 ft	NR	NR		A	NR		NR	NR		
	>60 Deg from Vertical (NOTE 3)	Glass	NL	Retained	Yes	ALL	B	1	1 w	0.2	1	10 min	Glass which is designed per <60 degrees category which requires access equipment shall be appropriately signed and/or fenced.
			NL	NFB	Yes	1	D	1	1 w	0.2	1	10 min	Testing required unless: 3 layers of glass of which as a minimum, the lower 2 must be laminated
	HORIZONTAL	Flooring panel or stair tread with LL - Controlled spaced where rope off will happen quickly in the case of breakage	NL	NFB	Yes	1	F	1	1 w	0.45	1	10 min	ASTM E2751 as alternate method
		Flooring panel or stair tread with LL and protected edges - Un-controlled spaces where rope off may NOT happen quickly in the case of breakage	NL	NFB	Yes	1	F	1	1 mo.	0.67	1	1 day	ASTM E2751 as alternate method,
			NL	Retained	Yes	ALL	F	1	1 mo.	0.45	1	1 hr	ASTM E2751 as alternate method,
	SECONDARY SYSTEMS: STACKED GLAZING (NOTE 4)	Stacked glazing (vertical , <15 deg from vertical)	NL	Retained	Yes	1 ply	F	1.2	1 mo.*	1	1	1 min	Needs alternative load path in case of breakage and/or replacement. Need to define appropriate stability considerations in both undamaged and damaged condition.
						1 lite	F	1.2	1 mo.*	0.67	1	1 min	Need to define silicone performance in temporary conditions.
						1 unit	F	1.2	1 mo.*	0.67	1	1 min	Alternative load paths for loss of units and replacement. Procedure for dealing with breakage in building maintenance manual.
			10ft	NR	NR		A						Top of the highest piece supported
		Glass walls supporting (glass) roof/ceiling	NL	Retained	Yes	1 unit	G	1	1 mo.*	0.67	1	1 min	Designer to consider reasonable damage scenarios
	FINS AND BEAMS NOT PUBLICLY TRAFFICABLE	Vertical Fins	18 ft	NR	NR		D						Heat soak testing recommended for monolithic FT glass >10ft high
		Glass fins/beams <15 deg from vertical	10ft	NR	NR		A						Top of the highest piece supported
			NL	refer <60									
		Glass Fins/ Beams <60 from vertical (with fall arrest and/or access device not resting on the glass)	NL	NFB	Yes	1	B	1	1 mo.	0.2	NA		
			NL	No Fall	Yes	All	B	1	1 mo.	0.2	NA		Commentary: face glass supports fin not fin supporting face glass: system performance load not element.
		Glass Beams > 60 deg from vertical	NL	NFB	Yes	1	G	1	1 mo.	0.2	1	1 hr	Publically Trafficable
				Retained	Yes	All	E	1	1 mo.	0.2	1	1 day	
		Glass Fins/Beams in Dual System with alternate load path	NL	No Fall	Yes*	Any	B	1	1 mo.	0.32	0**	1 hr	*Load redistributes to alternative load path **No LL
			NL	No Fall	Yes*	Any	D	1	1 mo.	0.67	1	1 hr	*Load redistributes to alternative load path
	HORIZONTAL OR LIVE LOADS	Stair Stringers (beams) - not main egress only	NL	NFB	Yes	1	H	1	1 mo.	0.67	1	1 day	
		Stair Stringers (beams)	NL	Retained	Yes	All	F	1	1 mo.	1	1	1 day	
	PRIMARY SYSTEMS	Primary elements, part of main stability system	NL	NFB	Yes	1	F	1.2	1 mo.	1	1	1 day	
				Retained	Yes	All	E	1	1 mo.	1	1	1 day	
				Retained	Alt Path	All	C	1	1 mo.	1	1	1 day	Redundancy provided by alternate load path.
		Primary elements, part of main stability system	NL	NFB	Yes	1	F	1.2	1 mo.	1	1	1 day	
				Retained	Yes	All	E	1	1 mo.	1	1	1 day	
				Retained	Alt Path	All	C	1	1 mo.	1	1	1 day	Redundancy provided by alternate load path.
GLASS RISK CATEGORY G-III	INFILL ELEMENTS: GENERAL	Glass not over trafficable area and not trafficable without fall arrest device	10 ft	No Fall	NR		A	1	1 w	NR	NR		The designer may exercise discretion where fall from <10ft. or is acceptable or desirable
			NL	No Fall	NR		A	1	1 w				
	VERTICAL	Glass with unsupported and unsealed vertical edges	10 ft	No Fall	NR		A	1	1 w				
			NL	No Fall	NR		A	1	1 w				
		Doors	10ft	NR	NR	NR	A				NR		
			NL	Retained	Yes	1	B	1	1 w	0.32	NR		
			NL	No Fall	NR	All	B	1	1 w		NR		
	<15 Deg from Vertical without barrier loads	4 sided supported windows and 2/3 side supported windows with structural silicone seals to unsupported edges.	NL	No Fall	NR		A	1	1 w				Refer E1300/IBC for alternative methods; laminated and retained
		Glass with unsupported and unsealed edges <15 deg from vertical and 1 Sided supported elements	10 ft	NR	NR		A				NR		
			NL	No Fall	Yes	All	A	1	1 w		NR		
			NL	Retained	Yes	1	A	1	1 w	0.32	NR		
	<60 deg from Vertical (NOTE 1)	4/3/2 sided supported windows	NL	NFB	Yes	1	B	1	1 w	0.32	1	10 min	
			NL	No Fall	NR	All	C	1	1 w		NR		
			NL	Retained	Yes	All	B	1	1 w	0.32	1	10 min	
	Barrier (<60 Deg from vertical) (NOTE 2)	Glass with barrier load >30" drop beyond barrier	NL	NFB	Yes	1	F	1	1 w	0.32	0.8 /0.5**	10 min	If there is a potential for injury (>30 drop beyond barrier) then there needs to be post failure capacity. ** separate factors for point loads?
			NL	No Fall	Alt Path	All	F	1	1 w		1	10 min*	A rail capable of bridging the potential opening satisfies redundancy requirements. * on the alternate load path.
			NL	Retained	Yes	All	F	1	1 w	0.32	0.8 / 0.51	10 min	Less than <4" opening
		Glass with barrier load <30" drop beyond barrier	10 ft	NR	NR		B						
	>60 Deg from Vertical (NOTE 3)	Glass	NL	NFB	Yes	1	F	1.2	1 w	0.2	1	10 min	Triple unless tested per E2751?
			NL	Retained	Yes	ALL	D	1.2	1 w	0.2	1	10 min	Testing TBC
	HORIZONTAL	Flooring panel or stair tread with LL - Controlled spaced where rope off will happen quickly in the case of breakage	NL	NFB	Yes	1	F	1	1 w	0.45	1	1 hr	ASTM E2751 as alternate method
		Flooring panel or stair tread with LL and protected edges - Un-controlled spaces where rope off may NOT happen quickly in the case of breakage	NL	NFB	Yes	1	F	1	1 mo.	0.8	1	1 day	ASTM E2751 as alternate method,
			NL	Retained	Yes	ALL	D	1	1 mo.	0.8	1	1 hr	ASTM E2751 as alternate method,
	SECONDARY SYSTEMS: STACKED GLAZING (NOTE 4)	Stacked glazing (vertical , <15 deg from vertical)	NL	Retained	Yes	1 ply	F	1.2	1 mo.*	1	1	1 min	Needs alternative load path in case of breakage and/or replacement. Need to define appropriate stability considerations in both undamaged and damaged condition.,
						1 lite	F	1.2	1 mo.*	0.67	1	1 min	Need to determine silicone performance in temporary conditions.
						1 unit	F	1.2	1 mo.*	0.67	1	1 min	Alternative load paths for loss of units and replacement. Procedure for dealing with breakage in building maintenance manual.
			10 ft	No Fall	No		D						
		Glass walls supporting (glass) roof/ceiling	NL	Retained	Yes	l unit	H	1	1 mo. to alt load path*	0.67	1	1 min	
	Fins and Beams not publically trafficable	Vertical fins	18 ft	NR*	NR		E			0.2*			* No fall of any element supported by the fin. Heat soak testing recommended for monolithic FT glass >10ft high
		Glass fins/beams <15 deg from vertical	10ft	No Fall	NR		B			0.2			Face glass supports damaged fin not fin supporting face glass: system performance load not element.
			NL	Refer <60 deg options									
		Glass Fins/ Beams <60 from vertical (with fall arrest and/or access device not resting on the glass)	NL	NFB	Yes	1	C	1	1 mo.	0.32	NA		Live load to be supported by alternate load paths
			NL	No Fall	Yes	All	C	1	1 mo.	0.32	NA		
		Glass Beams > 60 deg from vertical	18 ft*	NFB	Yes	1	G	1	1 mo.	0.67	1	1 hr	*Maintenance only
			NL	NFB	Yes	1	G	1	1 mo.	1	1	1 hr	Publically Trafficable
			NL	NFB	Yes	2	G	1	1 mo.	0.67	1	1 hr	Publically Trafficable
			NL	Retained	Yes	All	E	1	1 mo.	0.5	1	1 day	
		Glass Fins/Beams in Dual System with alternate load path	NL	No Fall	Yes*	Any	C	1	1 mo.	0.67	1	1 hr	*Load redistributes to alternative load path
	Horizontal or supporting surfaces with LLs	Stair stringers (beams) - not main egress only	NL	NFB	Yes	2	H	1	1 mo.	1	1	1 day	
		Stair stringers (beams)	NL	Retained	Yes	All	F	1	1 mo.	1	1	1 day	
	PRIMARY SYSTEMS	Primary elements, not part of main stability system	NL	NFB	Yes	1	H	1.3	3 mo.	1	1	1 day	
				Retained	Yes	All	F	1.2	1 mo.	1	1	1 day	
				Retained	Alt Path	All	F	1.2	1 mo.	1	1	1 day	Redundancy provided by alternate load path.
		Primary elements, part of main stability system	NL	NFB	Yes	1	H	1.3	2 mo.	1	1	1 day	
			NL	Retained	Yes	All	F	1.2	2 mo.	1	1	1 day	
			NL	Retained	Alt Path	All	F	1.2	2 mo.	1	1	1 day	Redundancy provided by alternate load path.
GLASS RISK CATEGORY G-IV	INFILL ELEMENTS	<15 Degrees from Vertical	NL	Retained	Yes	All	B	1	3 mo.	0.67	1	10 min	
		<60 deg from Vertical (NOTE 1)	NL	Retained	Yes	All	1	1	3 mo.	0.67	1	10 min	
		Barrier (<60 Deg from vertical) (NOTE 6)	NL	Retained	Yes	All	C	1	3 mo.	0.67	1	10 min	If there is a potential for injury (>30 drop beyond barrier) then there needs to be post failure capacity.
		Glass with barrier load >30" drop beyond barrier	NL	Retained	Yes	All	F	1	3 mo.	0.67	1	10 min	A rail capable of bridging the potential opening satisfies redundancy requirements. Less than <4" opening
		Doors	10ft	NL	NL	NL	A						Where removal of the door is required for egress, doors without retention may be used provided loss of envelope is acceptable to the building usage.
			NL	Retained	Yes	All	D	1	1 mo.	0.67	1	10 min	
		>60 Deg from Vertical (NOTE 3)	NL	NFB	Yes	1	F	1.2	3 mo.	1	1	1 hr	Triple unless tested per E2751?
			NL	Retained	Yes	ALL	D	1.2	3 mo.	0.67	1	1 hr	Testing TBC
		Horizontal flooring panel or supporting Live Load	NL	NFB	Yes	2	F	1	3 mo.	1	1	1 hr	ASTM E2751 as alternate method
			NL	Retained	Yes	ALL	F	1	1 mo.	0.67	1	1 hr	ASTM E2751 as alternate method,
	SECONDARY SYSTEMS: Fins and Beams - Not publicly trafficable	Stacked Glazing	NP										
		Glass Fins/ Beams <60 from vertical (with fall arrest and/or access device not resting on the glass)	NL	Retained	Yes	All	D	1	1 mo.	1	1	1 hr	
		Glass Beams > 60 deg from vertical	NL	Retained	Yes	All	F	1	1 mo.	1	1	1 day	
		Glass Fins/Beams in Dual System with alternate load path	NL	No Fall	Yes*	Any	D	1	3 mo.	1	1	1 hr	*Load redistributes to alternative load path
	Horizontal or supporting Live Loads	Stair stringers (beams) - not main egress only	NL	Retained	Yes	All	H	1	3 mo.	1	1	1 day	
		Stair stringers (beams)	NL	Retained	Yes	All	H	1	3 mo.	1	1	1 day	
	PRIMARY SYSTEMS	Primary elements, not part of main stability system	NL	NFB	Yes	2	H	1.3	3 mo.	1	1	1 day	
			NL	Retained	Yes	All	F	1.2	3 mo.	1	1	1 day	
			NL	Retained	Alt Path	All	F	1.2	3 mo.	1	1	1 day	Redundancy provided by alternate load path.
		Primary elements, part of main stability system	NL	Retained	Yes	All	H	1.3	3 mo.	1	1	1 day	
			NL	Retained	Alt Path	All	F	1.3	3 mo.	1	1	1 day	Redundancy provided by alternate load path.

Table 7.5

Reliability Adjustment Factor, G_R

CODE	β	AN	HS	FT
A	2.50	0.85	0.85	0.85
B	3.00	0.93	0.89	0.89
C	3.25	0.97	0.91	0.90
D	3.50	1.00	0.93	0.91
E	3.75	1.06	0.96	0.94
F	4.00	1.11	0.99	0.95
G	4.25	1.16	1.01	0.97
H	4.50	1.21	1.04	0.99

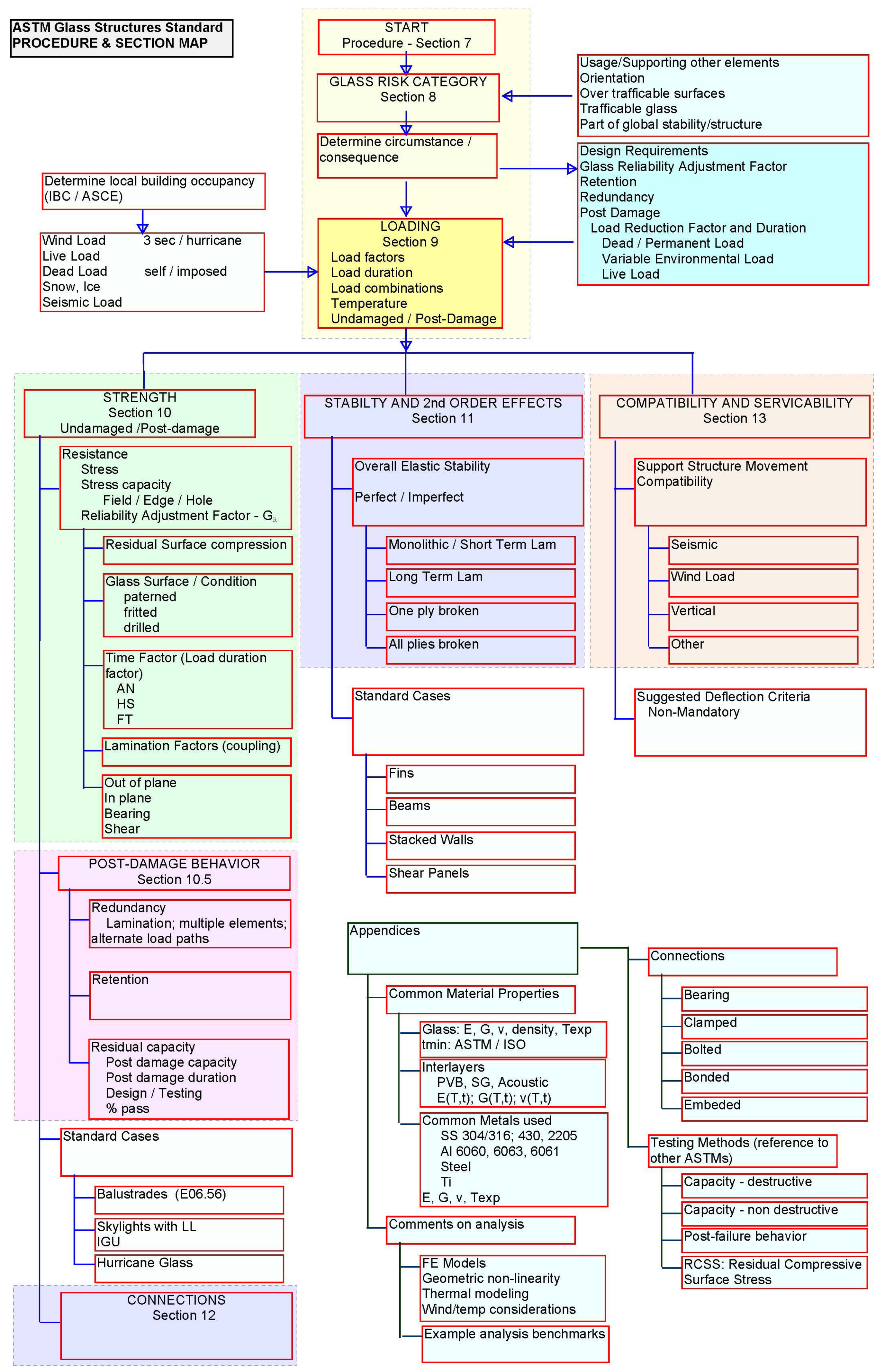
Legend

NL:	No Limit - May be used at any height
NR:	No Requirement for retention/redundancy
No Fall:	Glass may dislodge from support system on 1 or more edges, but cannot fall through a publicly trafficable space with a swing arc of 7ft above a trafficable surface
Retained:	No Dislodgement from opening
Alt Path:	Redundancy is achieved by redistribution of loads to an alternative load path
NP:	Not Permitted

Table 7.4

	Load Durations	In Service	Post-Damage G-I (In-fill / Secondary / Primary)	G-II (In-fill / Secondary / Primary)	G-III (In-fill / Secondary / Primary)	G-IV (In-fill / Secondary / Primary)
	DEAD LOADS	Permanent	None	See Main Table		
VARIABLE LOADS	Wind	3 sec	None	3 sec		
	Hurricane*	10 min	None	3 min		10 min
	Atmospheric pressure	1 wk	None	Determine by Engineer		
	Temperature	12 hr	None	Determine by Engineer		
	Snow	1 mo	None	1 mo		
	Ice	1 mo	None	1 mo		
	Seismic	3 min	None	3 min		
LIVE LOADS	Public - uncontrolled	10 min	NA	See Main Table		
	Public - controlled	10 min				
	Maintenance only	10 min				

Post-Damage Load Reduction Factor	Comment	Example Assembly	Capacity with 1 ply broken
0	Appropriate to areas with very limited risk due to breakage	Monolithic	Nil
0.2	Similar to ASCE-7 (2005) Extraordinary Loads for damaged structures. Wind Load Mean Recurrence Interval (MRI) ~0.7 years. Appropriate to systems with limited risk and rapid make-safe or replacement	2 ply – 1 ply broken Load out of plane	≥0.25 for simply supported glass
0.45	Load out of plane Appropriate to systems with limited risk and near term replacement	2 ply – 1 ply broken (Load in plane) or 3 ply – 1 ply broken (Load out of plane)	~0.45 - 0.5
0.67	Wind load MRI ~50 years. Appropriate to systems requiring some continued reliability at service loads Similar to ASTM 2751, no further breakage at design load with critical ply broken	3 ply – 1 ply broken Load in plane	~0.67
1	Wind load MRI ~700 years. Where full capacity in damaged state is important.	Sacrificial ply	~1.0



Basis	I: Target Reliability	I: Code	II: Target Reliability	II: Code	III: Target Reliability	III: Code	IV: Target Reliability	IV: Code
Favorable post damage behavior Satisfies post-damage design load with **all plies broken**	β = 2.5	**A**	β = 3.0	**B**	β = 3.25	**C**	β = 3.5	**D**
No progression of damage **No further breakage (NFB)** with nominated number of plies broken at post-damage design load	β = 3.0	**B**	β = 3.5	**D**	β = 3.75	**E**	β = 4.0	**F**
Fall control only **No fall** through or into trafficable space greater than 3m	β = 3.5	**D**	β = 4.0	**F**	β = 4.25	**G**	β = 4.5	**H**
Example of reliability adjustment strategies	**G-II** Lower consequence; One column to left of glass risk class		**G-II** Secondary structure; Column matches glass risk class		**G-II Primary and Live** Higher consequence; One column to right of glass risk class		Highest consequence; Special Cases	